MiniBooNE ν_μ and $\overline{\nu}_\mu$ disappearance results

Kendall Mahn
Columbia University

Overview

1) Neutrino oscillation
2) MiniBooNE experiment
3) MiniBooNE-only neutrino disappearance analysis
4) Antineutrino disappearance analysis
5) Improvements to disappearance analysis
6) Conclusion

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Neutrino oscillation

Neutrinos "oscillate" because the flavor state of the neutrino, ν_α, is related to the mass states, ν_i, by a mixing matrix, $U_{\alpha i}$

$$|\nu_i> = \sum U_{\alpha i} |\nu_\alpha>$$

Since there are three observed flavors of neutrinos (ν_e, ν_μ , ν_τ), the mixing

matrix, $U_{\alpha i}$, contains three mixing angles (θ_{12},θ_{23}, θ_{13}) and a CP violating phase δ. It can be factorized into three blocks, each corresponding to two neutrino mixing.

$$\boxed{U_{\alpha i} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}$$

$c_{ij}= \cos\theta_{ij}$, $s_{ij}= \sin\theta_{ij}$

Neutrino oscillation

As the states propagate in time, the neutrino mass states interfere:

$$|\nu_\alpha(t)> \; = \sum -\sin\theta_{ij}\,|\nu_i> + \cos\theta_{ij}\,|\nu_j>$$

The probability to observe ν_β with a pure ν_α sample is:

$$P_{\alpha\to\beta} = |<\nu_\beta|\nu_\alpha(t)>|^2 = \sin^2 2\theta_{ij} \sin^2\left(1.27\frac{\boxed{\Delta m^2_{ij}}\boxed{L}}{\boxed{E}}\right)$$

where L (km) is the distance traveled, E (GeV) is the energy of the neutrino and Δm^2 (eV^2) is the difference of the masses squared:

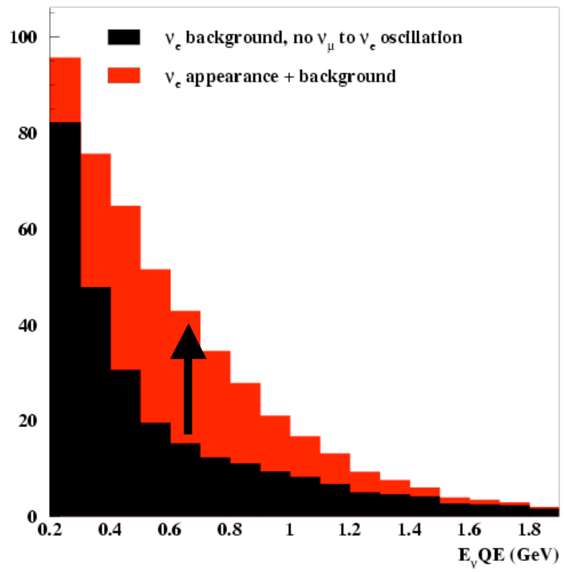
$$\Delta m^2_{ij} = m_i^2 - m_j^2$$

Choice of L and E chooses what range of Δm^2 the experiment is sensitive to, the size of the oscillations sets $\sin^2 2\theta$

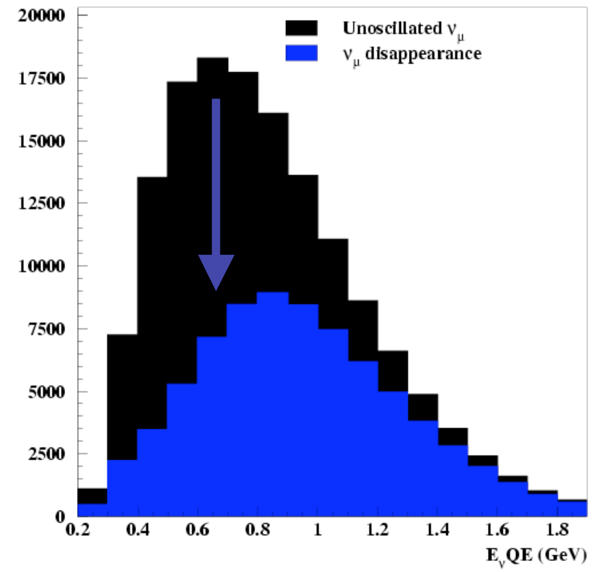
Disappearance and Appearance experiments

Starting with a ν_α beam, there are two ways to look for oscillation:

Appearance experiment
Detect more ν_β than expected



Disappearance experiment
Detect less ν_α than expected



Neutrinos at energy E_1 oscillate differently than at E_2 for the same L, creating a unique signature for oscillation vs energy

Reducing errors with a second detector

Source of error	**Total fractional error (%)**
pBe → π+ production (flux)	**4.0**
beamline and horn model (flux)	**4.3**
cross sections	**18.6**
detector model	**4.0**
total	**19.9**

Adding a second detector measures the flux x cross section to the level of uncorrelated errors between the two detectors

Start with 20% error

Remove flux, cross section, and beam errors: 20% → 4%

Add 5% uncorrelated errors: 4% + 5% = 6%

Normalization information

To search for disappearance, can use normalization or shape information

1) Normalization information:

Compare total number of events to expectation
(aka “counting experiment”)

K2K expected: 158 + 9.2 - 8.6 events at the far detector
but observed: 112 events

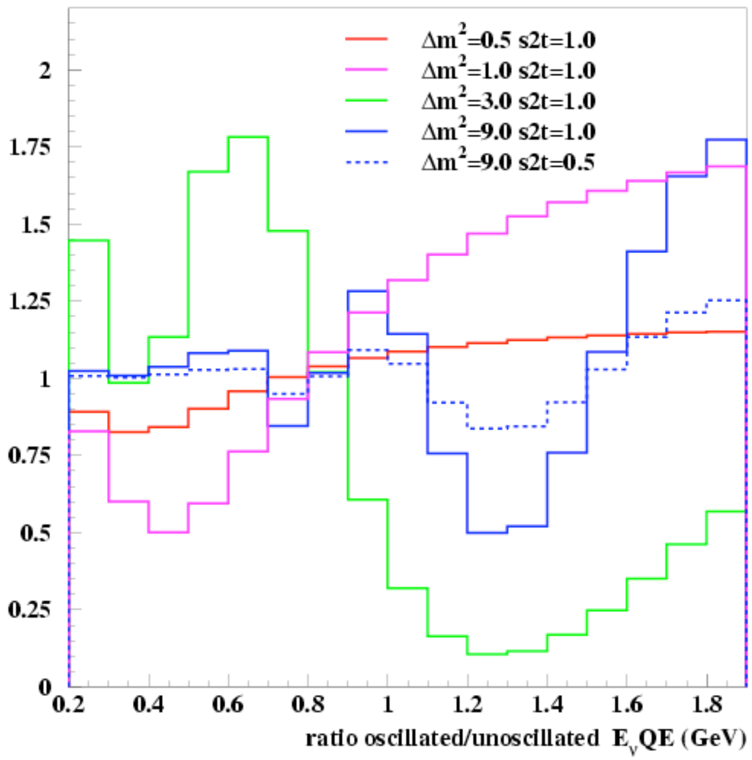
Normalization information provided by additional detectors
Limited by statistics at far detector

Shape information

To search for disappearance, can use normalization or shape information

2) Shape information:

Compare the energy distribution of events to no oscillation hypothesis



Ratio of oscillated events/ unoscillated events vs energy

- Δm^2 changes the periodicity of the oscillation (see Δm^2=1eV^2, Δm^2=3 eV^2)
- $\sin^2 2\theta$ changes the depth of the oscillation (see $\sin^2 2\theta$=1.0, $\sin^2 2\theta$=0.5)

MiniBooNE will make a one detector shape measurement

Oscillation observations

Plot of all oscillation experiments:

"Atmospheric": $\Delta m^2_{23} \sim 10^{-3} eV^2$,
$\sin^2 2\theta_{23} \sim 45°$

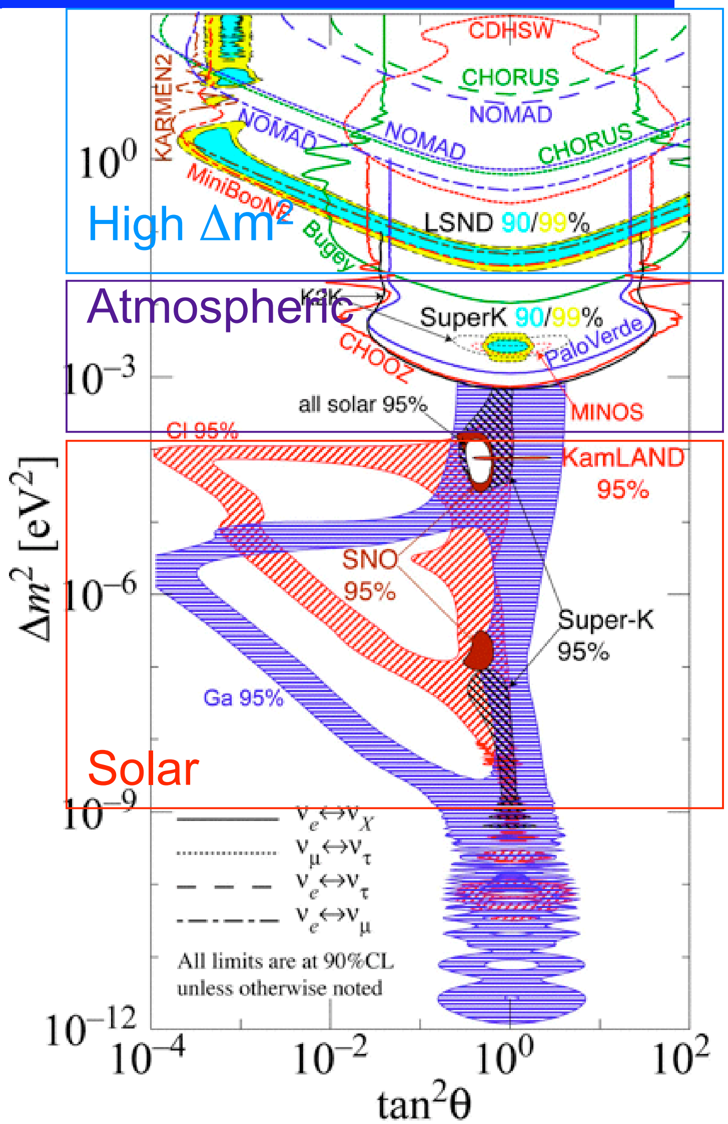
- With atmospheric ν: SuperK
- With Accelerator ν: MINOS

"Solar": $\Delta m^2_{12} \sim 10^{-5} eV^2$, $\sin^2 2\theta_{12} \sim 32°$

- With solar ν: SNO
- With reactor ν: KamLAND

"High Δm^2": $\Delta m^2 \sim 1\text{-}10 eV^2$

- CDHS (disappearance)
- CCFR (disappearance)
- LSND (appearance)



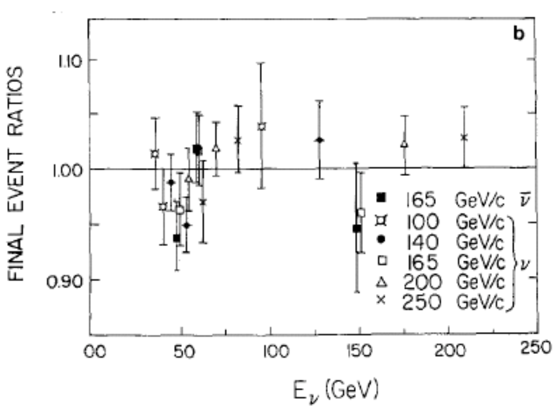
http://hitoshi.berkeley.edu/neutrino

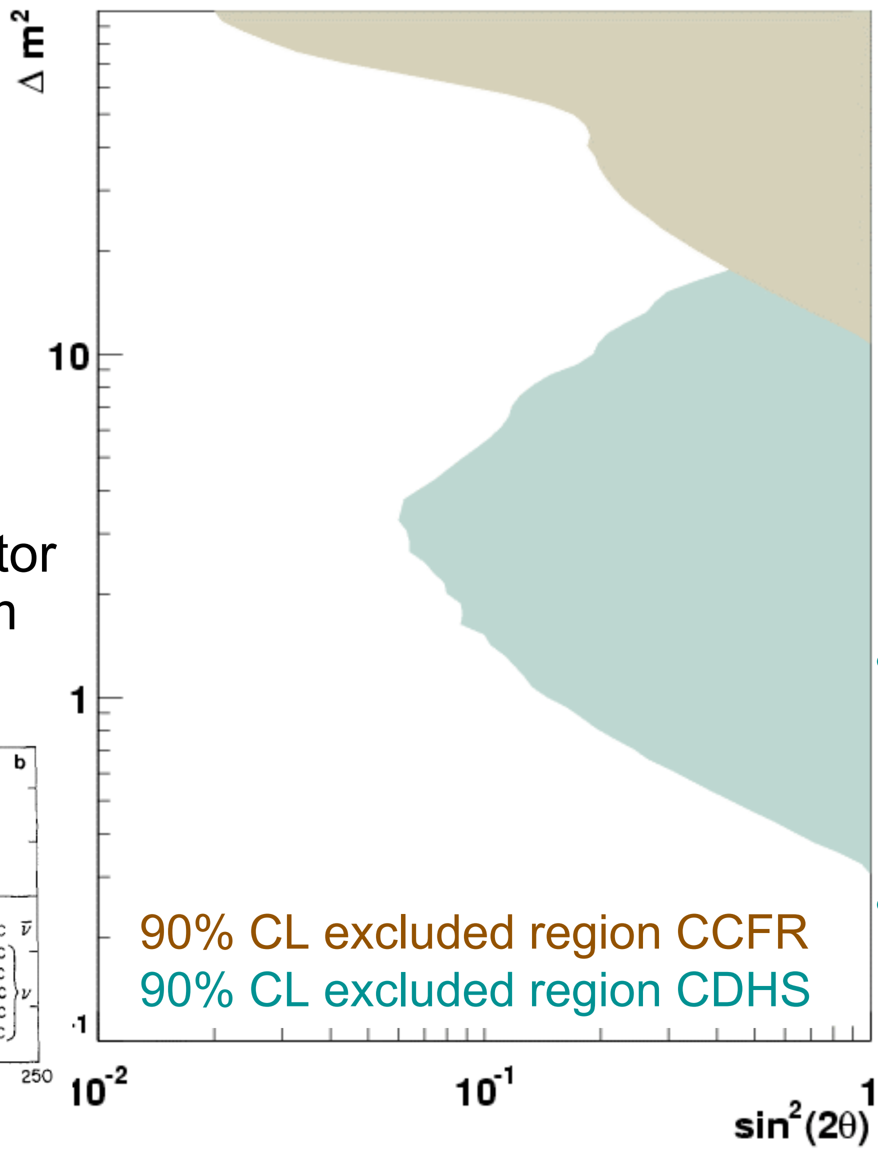
High Δm^2 disappearance expts

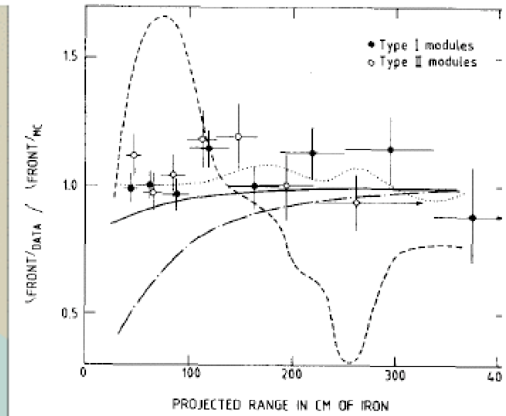
CCFR (FNAL E701)

I.E. Stockdale et al
Z.Phys.C27:53,1985

- Mono energetic meson beam produces dichromatic (~50, 160GeV) neutrino beam
- Two steel/scintillator detectors at 715m and 1116m







CDHS at CERN

F. Dydak et al.
Phys.Lett.B134:281,1984.

- 19.2 GeV protons on Be target produces ~3GeV neutrino beam
- Two iron/scintillator detectors at 130m and 885m

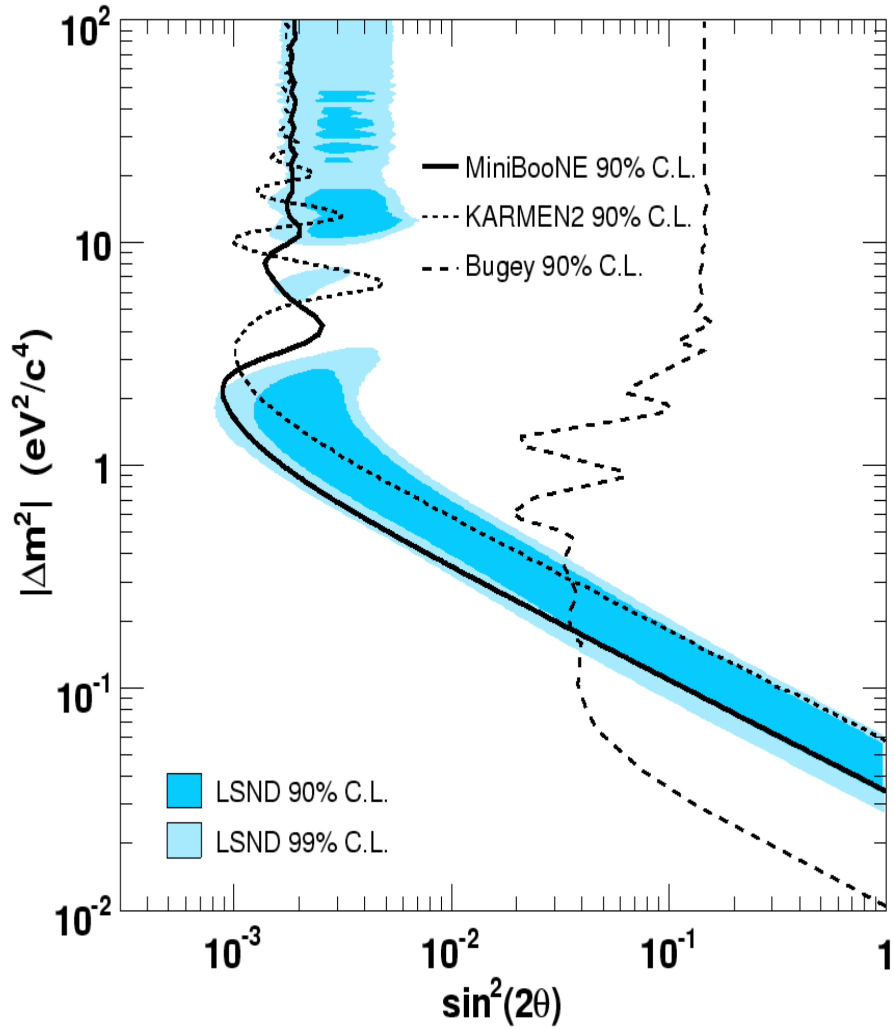
LSND ν_e appearance

LSND experiment

Observation of 3.8 σ excess of ν_e in $\bar{\nu}_\mu$ beam

Karmen, Bugey and MiniBooNE exclude the LSND parameter space

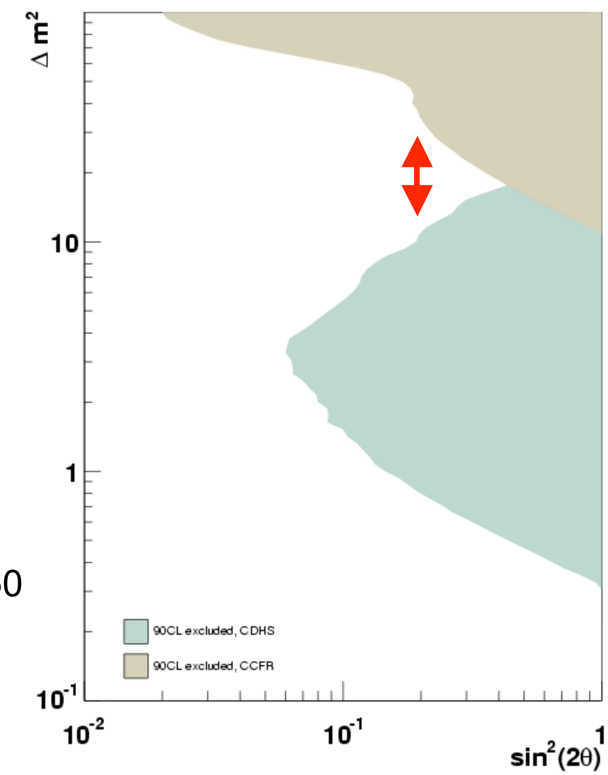
If $\bar{\nu}_e$ oscillate but ν_e do not, then exotic physics is needed to explain this signal



Sterile neutrinos

One explanation for the LSND oscillation signal is to add another "sterile" flavor of neutrino (or 2 or N) to the mixing matrix:
Adding 1 sterile neutrino is 3+1, adding N is 3+N

$$U_{\alpha i} = \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \vdots \\ \nu_s \end{pmatrix} \begin{pmatrix} U_{e1} & U_{e2} & \cdots & U_{eN} \\ U_{\mu 1} & U_{\mu 2} & \cdots & U_{\mu N} \\ U_{\tau 1} & U_{\tau 1} & \cdots & U_{\mu N} \\ \vdots & \vdots & \ddots & \vdots \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \vdots \\ \nu_N \end{pmatrix}$$



Disappearance expts (CDHS/CCFR/atmospheric) disfavor 3+1 already
Maltoni, Schwetz, Valle, Phys.Lett.B518:252-260,2001. hep-ph/0107150

3+2 models have large mixing and prefer the region where experimental limits are weakest
G. Karagiorgi et al, Phys.Rev.D75:013011,2007. hep-ph/0609177

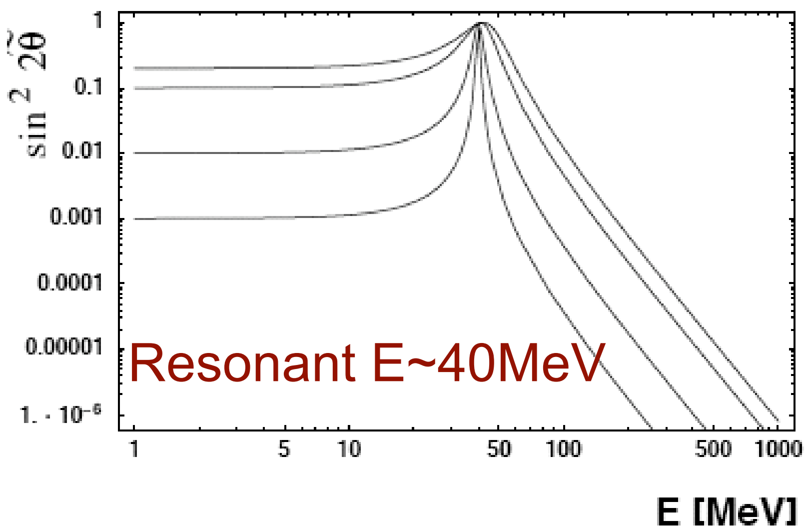
Motivation for neutrino disappearance

The observation of ν_μ disappearance could imply:

- sterile neutrinos G. Karagiorgi et al, Phys.Rev.D75:013011,2007. hep-ph/0609177
- neutrino decay Palomares-Ruiz, Pascoli, Schwetz, JHEP 0509:048,2005. hep-ph/0505216
- extra dimensions Pas, Pakvasa, Weiler, Phys.Rev.D72:095017,2005. hep-ph/0504096

When the path-length increases for active neutrinos in the bulk relative to sterile neutrinos, oscillations between sterile and active flavors are enhanced above a resonant energy, and suppressed below

A resonance energy between 30-400MeV explains all data in a 3+1 model



The lack of ν_μ disappearance also can constrain these models

Motivation for neutrino disappearance

The combination of ν_μ and $\overline{\nu}_\mu$ disappearance tests unitarity of the mixing matrix, and CPT

- If $\overline{\nu}_\mu$ disappear, but ν_μ do not would signal CPT violation
- Sterile neutrino models (3+1 or 3+2) can be CPT violating
  Barger, Marfatia, & Whisnant, Phys. Lett. B576 (2003) 303
- Introduction of a new light gauge boson
  Nelson, Walsh Phys .Rev. D77 033001 (2008) hep-ph/0711.1363
- Lorentz violation
  Katori, Kostelecky, & Tayloe, Phys. Rev. D74 (2006) 1050009
  P. Adamson et al, Phys. Rev. Lett. 101 151601 (2008) hep-ex/0806.4945

Motivation for neutrino disappearance

- The observation of ν_μ disappearance could imply new physics
- The lack of ν_μ disappearance constrains new physics models
- The combination of ν_μ and $\bar{\nu}_\mu$ disappearance tests unitarity and CPT

Can MiniBooNE add to the current disappearance limits?

YES! with both neutrinos and antineutrinos

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6) Conclusion

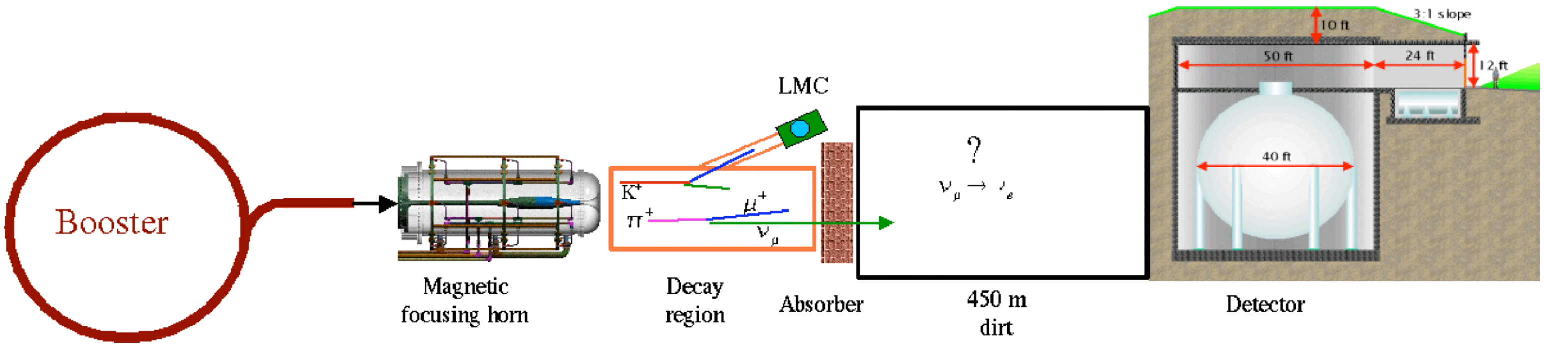
The MiniBooNE Collaboration

Y.Liu, D.Perevalov, I.Stancu
University of Alabama
S.Koutsoliotas
Bucknell University
E.Hawker, R.A.Johnson, J.L.Raaf
University of Cincinnati
T. L. Hart, R.H.Nelson, M.Tzanov
M.Wilking, E.D.Zimmerman
University of Colorado
A.A.Aguilar-Arevalo, L.Bugel, L.Coney,
Z. Djurcic, K.B.M.Mahn, J.Monroe, D.Schmitz
M.H.Shaevitz, M.Sorel
Columbia University
D.Smith
Embry Riddle Aeronautical University
L.Bartoszek, C.Bhat, S.J.Brice
B.C.Brown, D. A. Finley, R.Ford, F.G.Garcia,
C. Green, P.Kasper, T.Kobilarciik, I.Kourbanis,
A.Malensek, W.Marsh, P.Martin, F.Mills,
C.D.Moore, E.Prebys, A.D.Russell , P.Spentzouris,
R.J.Stefanski, T. Williams
Fermi National Accelerator Laboratory
D.C.Cox, T.Katori, H.Meyer, C.C.Polly, R.Tayloe
Indiana University
H.Ray, B. Osmanov
University of Florida
G.T.Garvey, A.Green, C.Green, W.C.Louis,
G.McGregor, G.B.Mills, V.Sandberg, R.Schirato,
R.Van de Water , D.H.White, G.P.Zeller
Los Alamos National Laboratory

R.Imlay, J.A. Nowak, W.Metcalf, S.Ouedraogo, M. Sung, M.O.Wascko
Louisiana State University
J.M.Conrad, G. Karagiorgi, V. Nguyen
Massachusetts Institute of Technology
J.Cao, Y.Liu, B.P.Roe, H.J.Yang
University of Michigan
A.O.Bazarko, E. M. Laird, P.D.Meyers, R.B.Patterson, F.C.Shoemaker, H.A.Tanaka
Princeton University
P.Nienaber ***Saint Mary's University of Minnesota***
J. M. Link ***Virginia Polytechnic Institute***
C.E Anderson, A.Curioni, B.T.Fleming,S.K. Linden, M. Soderberg
Yale University

MiniBooNE Experiment

Short baseline (L=~500m) designed to test LSND-like ν_e appearance



8.9 GeV/c protons on Be produce mesons which decay to neutrinos or antineutrinos

Changing the polarity of the horn focuses positive (negative) mesons and produces a neutrino (antineutrino) beam

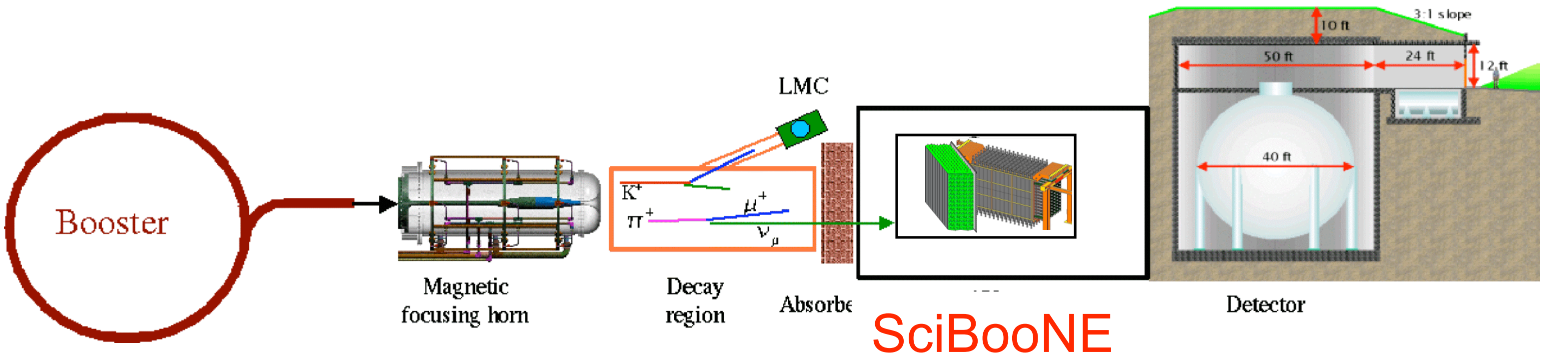
Data sets shown today are:

5.579e20POT neutrino mode (190,454 events)

3.386e20POT antineutrino mode (27,053 events)

MiniBooNE Experiment

Short baseline (L=~500m) designed to test LSND-like ν_e appearance



8.9 GeV/c protons on Be produce mesons which decay to neutrinos or antineutrinos

In 2007, the SciBooNE detectors were put into the beamline at 100m

Beamline Timeline

2/03 - 1/06: First results data run, neutrino mode

1/06-10/07: First antineutrino run period

5/29/07: SciBooNE begins data taking

Thank you Accelerator division!
from SciBooNE & MiniBooNE

10/07-4/08: Joint neutrino run with SciBooNE

4/08-now: Joint antineutrino run with SciBooNE

8/08: SciBooNE decommissioned

In MiniBooNE: ~1 ν per 1e15 POT

~ 0.2 $\bar{\nu}$ per 1e15 POT

In SciBooNE: ~5x closer, ~50x smaller

~0.5 ν per 1e15 POT

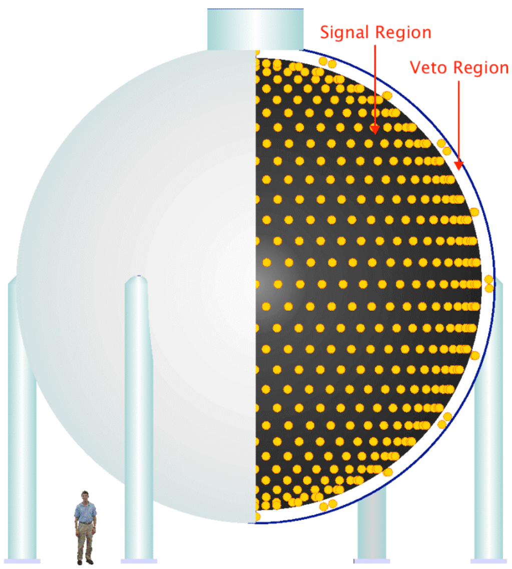
~ 0.1 $\bar{\nu}$ per 1e15 POT

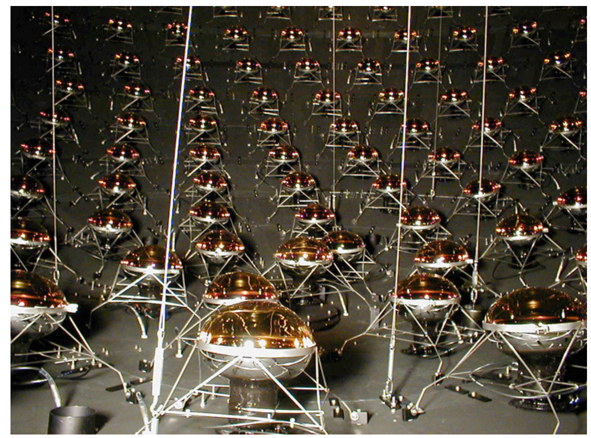
MiniBooNE Detector

The MiniBooNE detector is a ~1kton mineral oil Cherenkov detector

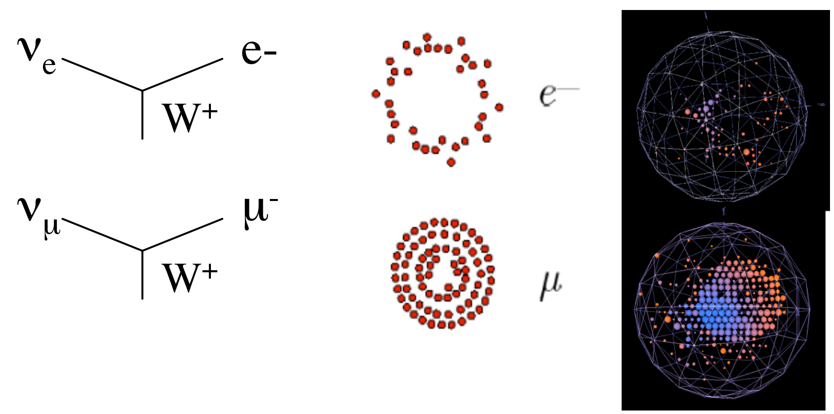
12 m diameter, 1280 inner PMTs, 240 outer 'veto' PMTs

MiniBooNE Detector

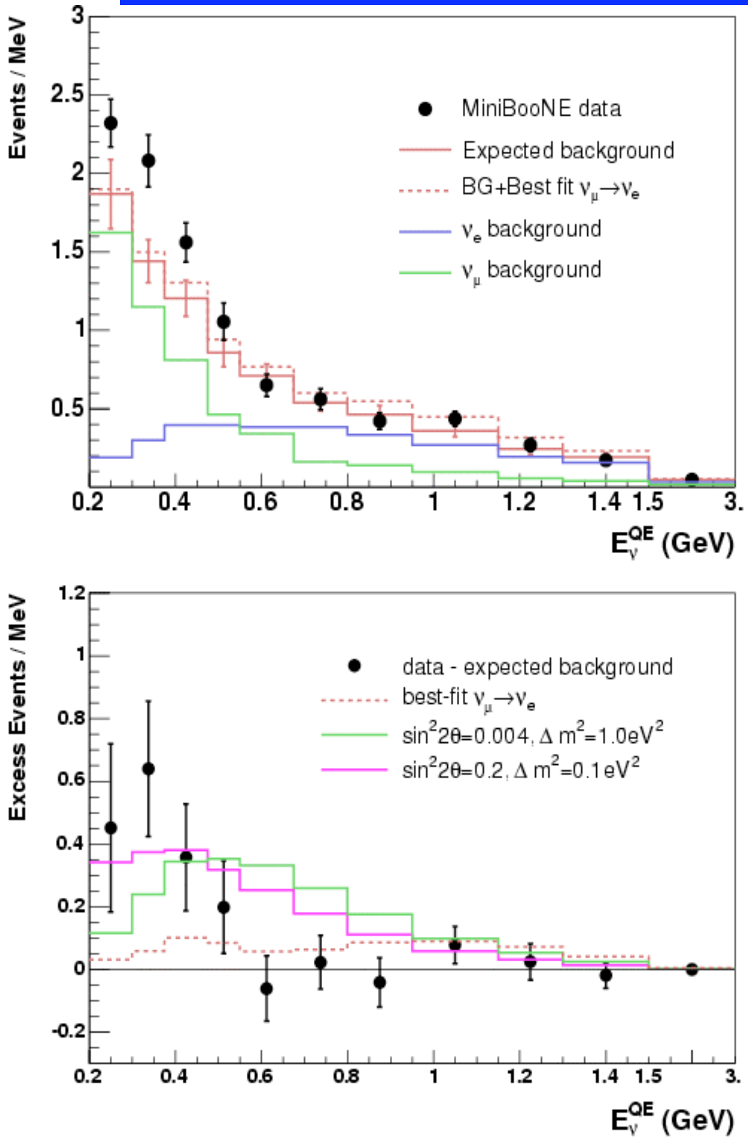




Use hit topology and timing to determine electron-like or muon-like Cherenkov rings and corresponding charged current neutrino interactions



MiniBooNE ν_e appearance results



- ν_e sample is consistent with expectation >475 MeV (0.6 σ excess)
- 3.0 σ excess at low energy (200-475 MeV)
  - Initial observation confirmed with later work (Aug 1st W&C)
  - Excess cannot be described based on a simple 2 ν mixing hypothesis
  - PRL forthcoming
- This result assumes no ν_μ disappearance

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ν_μ disappearance analysis plan

To do a ν_μ disappearance analysis with one detector, we need:

Event selection

\+

Prediction with systematic errors

flux, cross section, detector effects

\+

Disappearance fit machinery

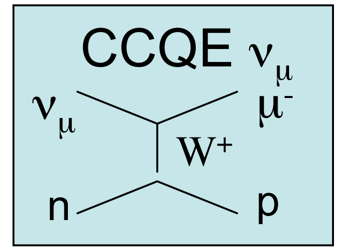
ν_μ disappearance sample

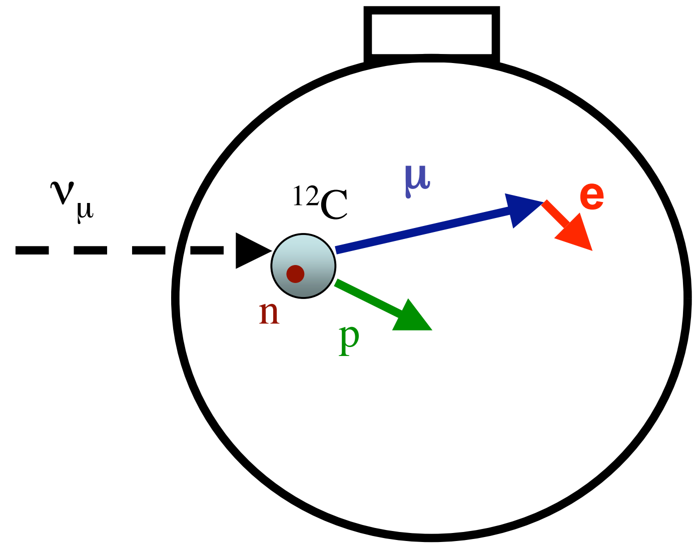
- Use Charged Current Quasi elastic events (CCQE) ν_μ events
  - Selecting on muon selects ν_μ
  - With just muon's energy, angle, can reconstruct neutrino energy

$$E_\nu(QE) = \frac{m_n E_\mu - \frac{1}{2} m_\mu{}^2}{|\, p_\mu \,| \cos\theta_\mu + m_n - E_\mu}$$

Tag single muon events and their decay electron

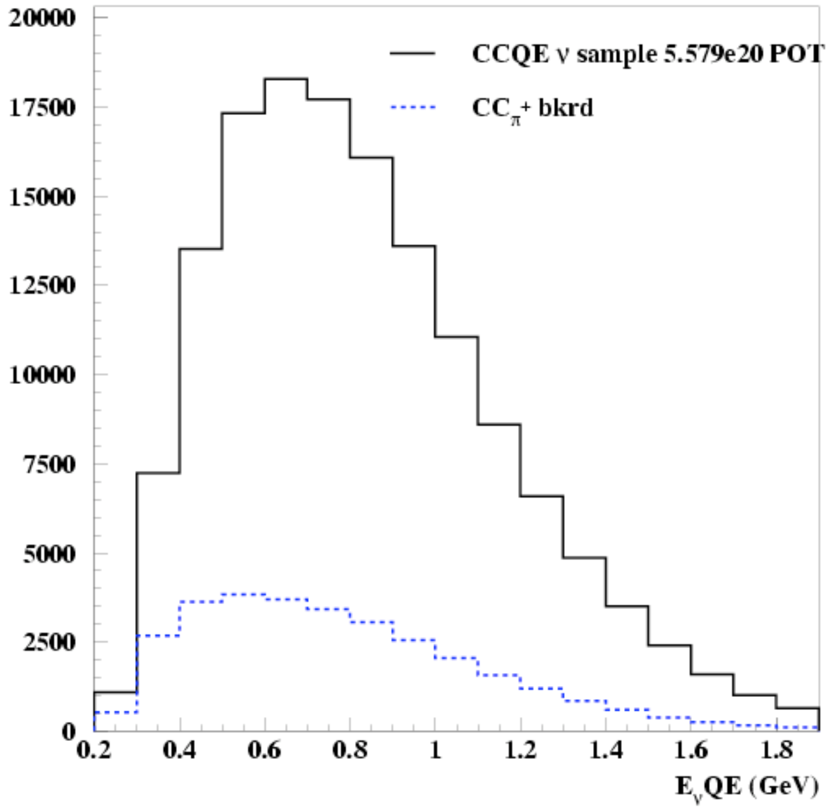
- 2 subevents (μ, then e) with minimal veto activity in both
- muon-like track, 2nd event below decay electron energy endpoint
- both events within fiducial volume



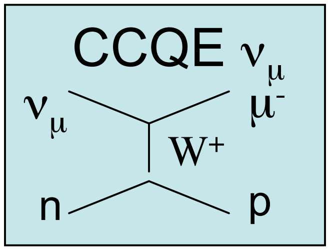


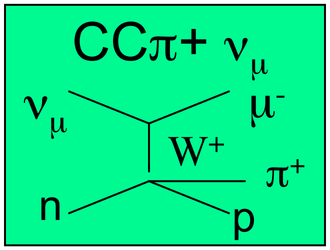
"Selecting muons in a Cherenkov detector is like shooting fish in a barrel"
- Aunt Edith

CCQE ν_μ selection



- Impressive neutrino sample: ~200k events, 74% CCQE purity





- Background is CCπ^+ where the pion is absorbed in the nucleus or detector
  - All events can oscillate, but misreconstruction of CCπ^+ as CCQE events mean CCπ^+ are shifted to low EνQE
- Pure neutrino sample, only 1.4% antineutrino content

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Flux prediction

Neutrino beamline is modeled in Geant4 hep-ex/0806.1449

p + Be target → meson production → focusing → decay → neutrinos

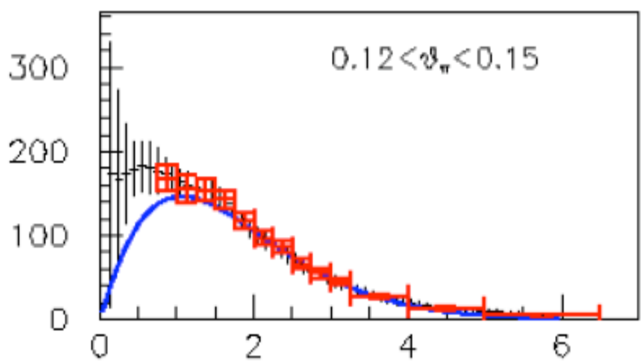
Included as systematic error:

1. Beam optics and targeting efficiency
2. p+Be elastic and inelastic cross sections
3. Production of mesons ($\pi^{+/-}$, $K^{+/-}$) from pBe interactions
4. Horn magnetic field

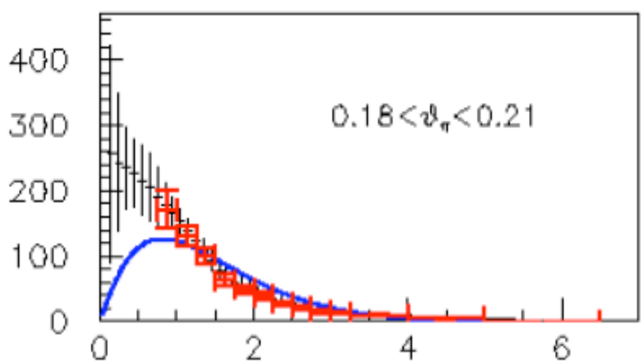
Largest sources of error are meson production and horn magnetic field

Meson Production Uncertainties

$d\sigma/dpd\Omega$ (mb c/[GeV sr])



p_π (GeV)



HARP data with errors in θ_π bins

MiniBooNE flux parameterization

The HARP experiment measured $p+Be \rightarrow \pi^+/\pi^-$ (hep-ex/0702024)

Use the HARP data and errors to produce different fluxes consistent with HARP

Propagate the new fluxes through to the neutrino spectrum and look at the effect on the CCQE ν_μ sample

88% of the CCQE ν_μ sample is within HARP's coverage; 99% is contained within HARP and θ_π > 0.210

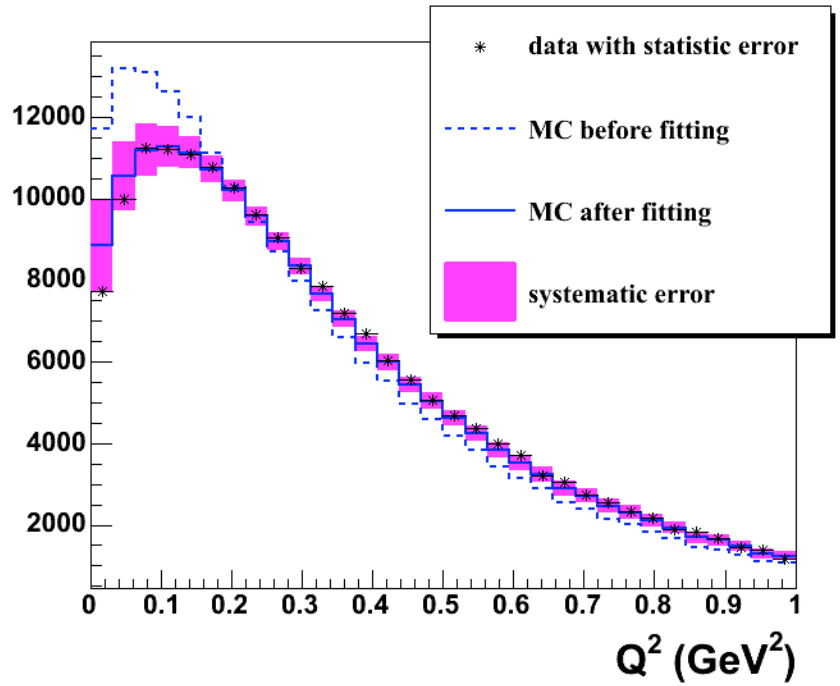
Cross section model and the disappearance result

For ν_e appearance result, we tuned the cross section model

Shape only fit in Q^2 using the CCQE ν_μ sample favored a higher axial form factor (M_A) and a new nuclear effect parameter, K, was introduced to model Pauli suppression or other effects at low Q^2
Phys. Rev. Lett. 100, 032301 (2008).

M_A = 1.23 +/- 0.20 GeV
K = 1.019 +/- 0.011

$$Q^2 = -m_\mu{}^2 + 2E_\nu(E_\mu - p_\mu \cos\theta_\mu)$$



Cross section model and the disappearance result

For ν_μ disappearance, we undo the tuning and set the uncertainties to cover the excursion in the world data and our own

World's data on deuterium: M_A=1.014 +/- 0.014 GeV

Bodek et al J.Phys.Conf.Ser.110:082004,2008. hep-ex/0709.3538

K2K CCQE σ on Carbon: M_A = 1.14+/- 0.11 GeV

F. Sanchez, NuInt07

K2K CCQE σ on Oxygen M_A = 1.20+/- 0.12 GeV

R. Gran et al., PRD74, 052002 (2006)

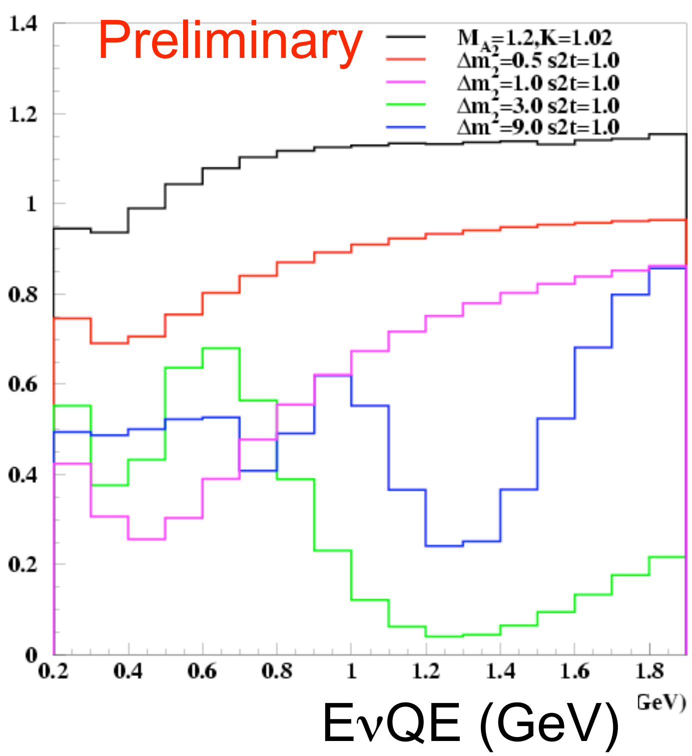
Using: M_A=1.0 +/-0.23 GeV, K=1.000+/- 0.0220

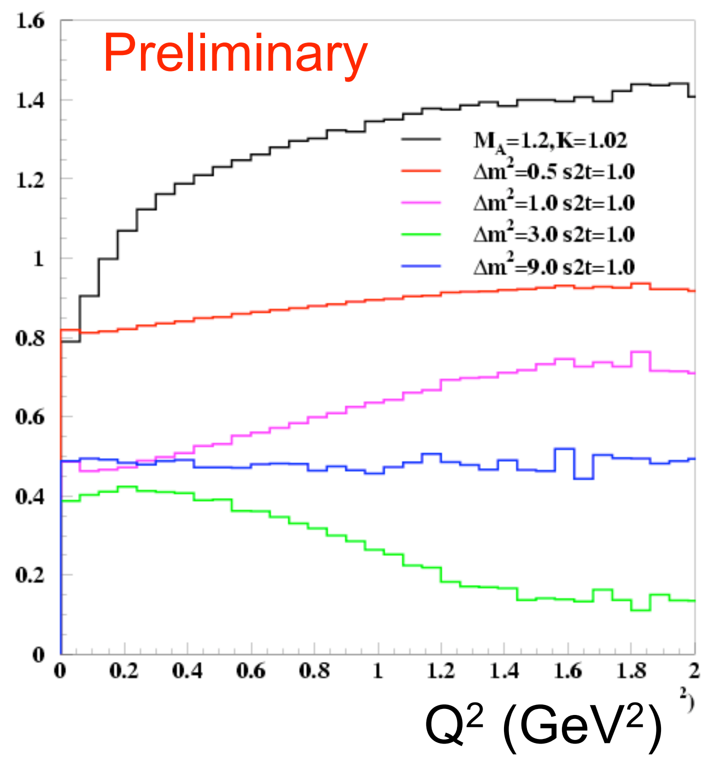
The cross section uncertainties also include uncertainties on the CCπ^+ cross section and pion charge exchange and absorption in the nucleus

Can the cross section model mask disappearance?

(M_A=1.2 GeV,K=1.02) / (M_A =1.0 GeV, K=1.0) induces a shape change similar to Δm^2=0.5 eV^2 in EνQE

But in Q^2, oscillations vanish while the effect of the cross sections is stronger

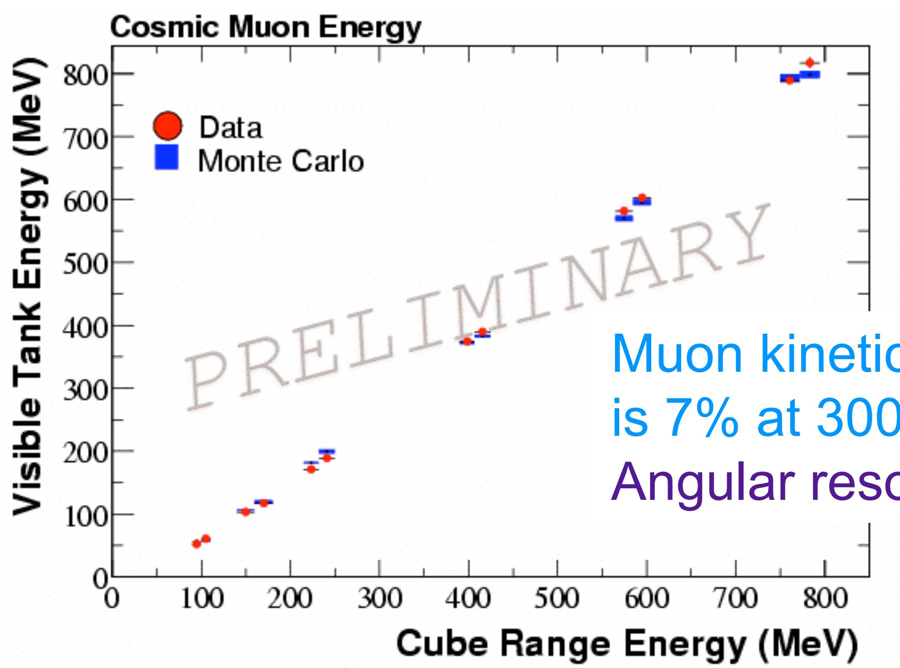




Detector uncertainties

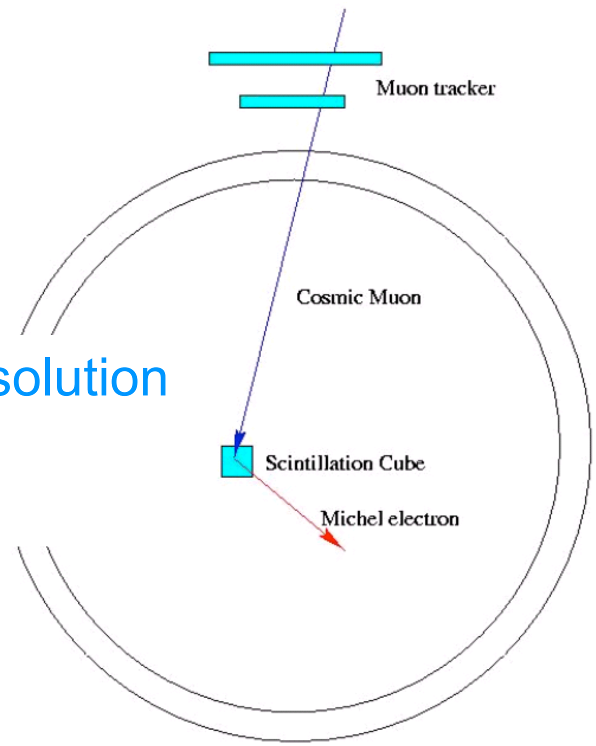
Muon hodoscope tracked incoming (10kHz) cosmic ray muons entering detector

Events which stopped in scintillation cubes provided known distance with which to calibrate muon energy in oil



Muon kinetic energy resolution is 7% at 300MeV

Angular resolution is 5°



Systematic error summary

Source of error	**Total fractional error (%) (counting experiment)**
pBe → π+ production (flux)	**4.0**
beamline and horn model	**4.3**
cross sections	**18.6**
detector model	**4.0**
total	**19.9**

Data = 190,454 events

MC (MA,K=1.0) = 145,085 +/- 20%

- The more one under predicts the data, the stronger the sensitivity to ν_μ disappearance becomes
- We under predict the data normalization by 1.5 σ
- In order to be conservative, we choose to perform a shape only disappearance fit
- Normalization information will be included with SciBooNE

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Disappearance fit machinery

Shape-only disappearance fit

Use Shape only Pearson's χ^2:

For each point in oscillation space compare the prediction, $p_i(\Delta m^2, \sin^2\theta)$, to the data, d_i, and sum over bins i and j

$$\underline{\chi^2} = \sum(\underline{d_i} - X\underline{p_i})M_{ij}^{-1}(\underline{d_j} - X\underline{p_j})$$

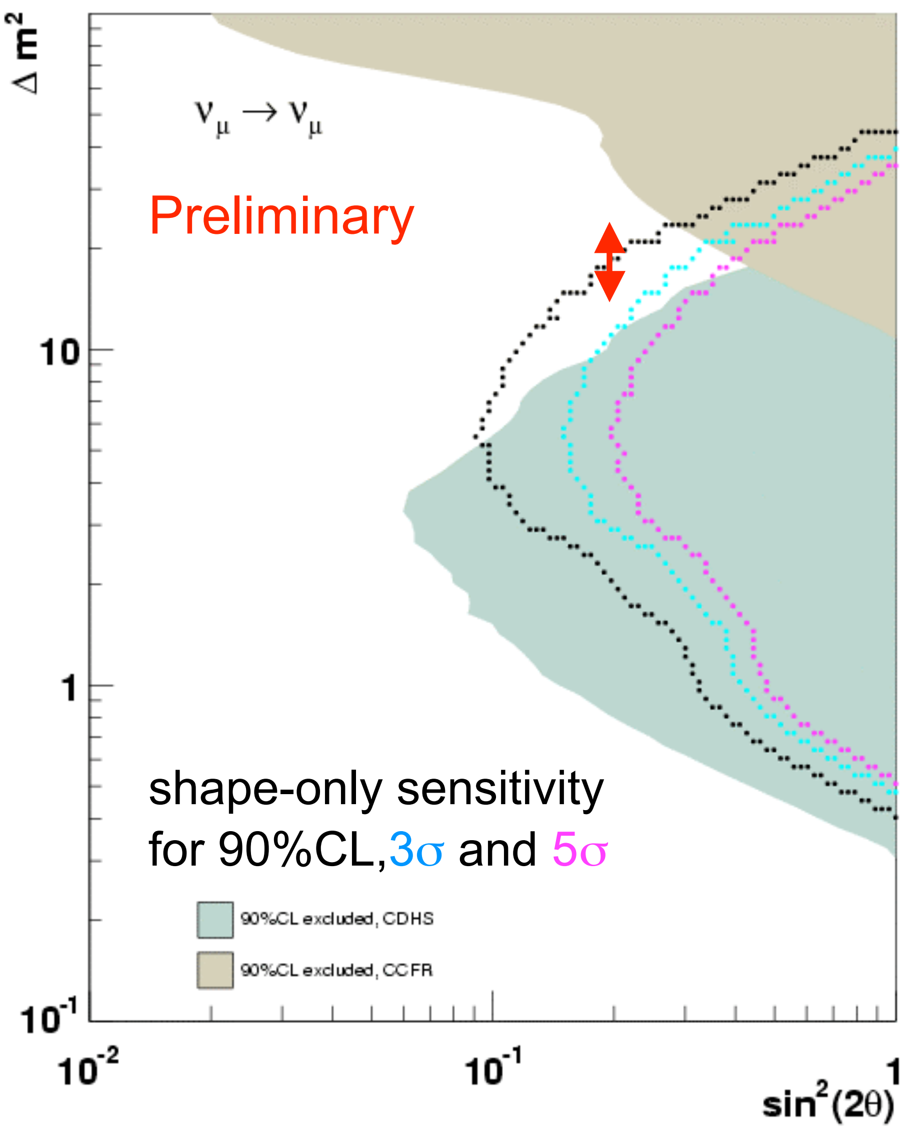
- M_{ij} is shape only (variations conserve events across all bins)
- $X(\Delta m^2, \sin^2\theta)$ renormalizes p_i to the total data events,

$$X(\Delta m^2, \sin^2 2\theta) = \sum d_i \Big/ \sum p_i$$

For Δm^2, $\sin^2\theta$ points where $\chi^2 > \chi^2$ (CL), draw that CL curve

For 16 bins, χ^2(90% CL) = 23.5

Sensitivity



The sensitivity is a fit to fake data which exactly agrees with prediction but all statistical and systematic uncertainties are included

A shape-only, single detector measurement is sensitive to ν_μ disappearance in the particular region favored by 3+2 models

Cross check: Frequentist $\Delta\chi^2$

Comparison between data (d_i) and prediction (p_i) relative to best fit across all Δm^2, $\sin^2\theta$ points

$$\chi^2 = \sum (d_i - Xp_i) M_{ij}^{-1} (d_j - Xp_j)$$

For each point, create 50 "fake experiments" using fluctuations consistent with the errors and calculate $\Delta\chi^2$ (Δm^2, $\sin^2\theta$, CL)

$$\Delta\chi^2(\Delta m^2, \sin^2 2\theta) = \chi^2(true = \Delta m^2, \sin^2 2\theta) - \chi^2(best)$$

For fit to real data, use $\Delta\chi^2$ (Δm^2, $\sin^2\theta$, CL) to generate CL curves

Fit data at each point as if it corresponds to that true point, calculate $\Delta\chi^2$

if $\Delta\chi^2 > \Delta\chi^2$ (Δm^2, $\sin^2\theta$, CL) for a given CL, draw curve

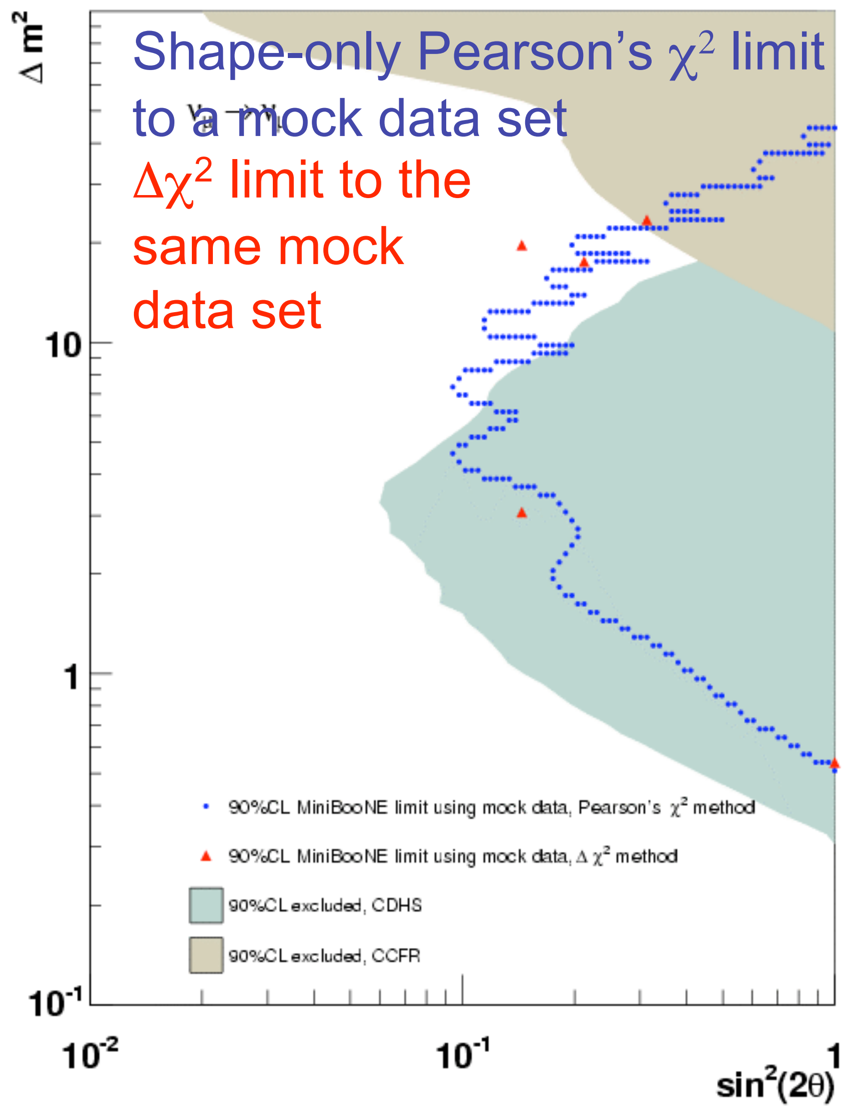
Procedure can be done with shape-only fits like Pearson's χ^2

Renormalize p_i at each point, matrix is shape only

Cross check: Frequentist $\Delta\chi^2$

Frequentist $\Delta\chi^2$ gives better sensitivity by mapping out distorted $\Delta\chi^2$ surface but is computing intensive

- $\Delta\chi^2$ ranges from ~4 degrees of freedom (dof) at low $\sin^2\theta$ to 1dof at high $\sin^2\theta$
- Approximately 1 hour of computing for each $\Delta\chi^2$ point shown, as compared to the ~1 minute needed for the Pearson's χ^2 limit

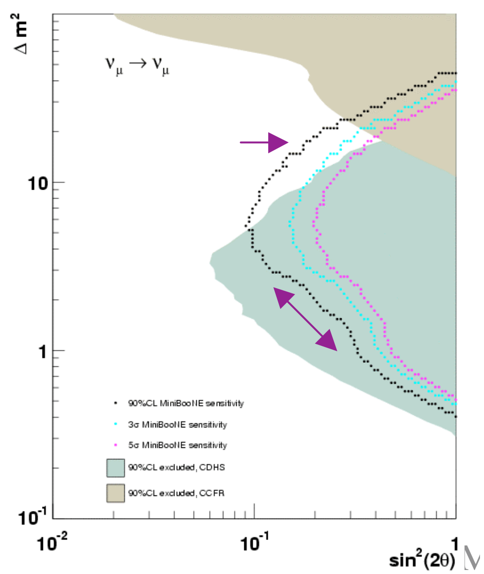


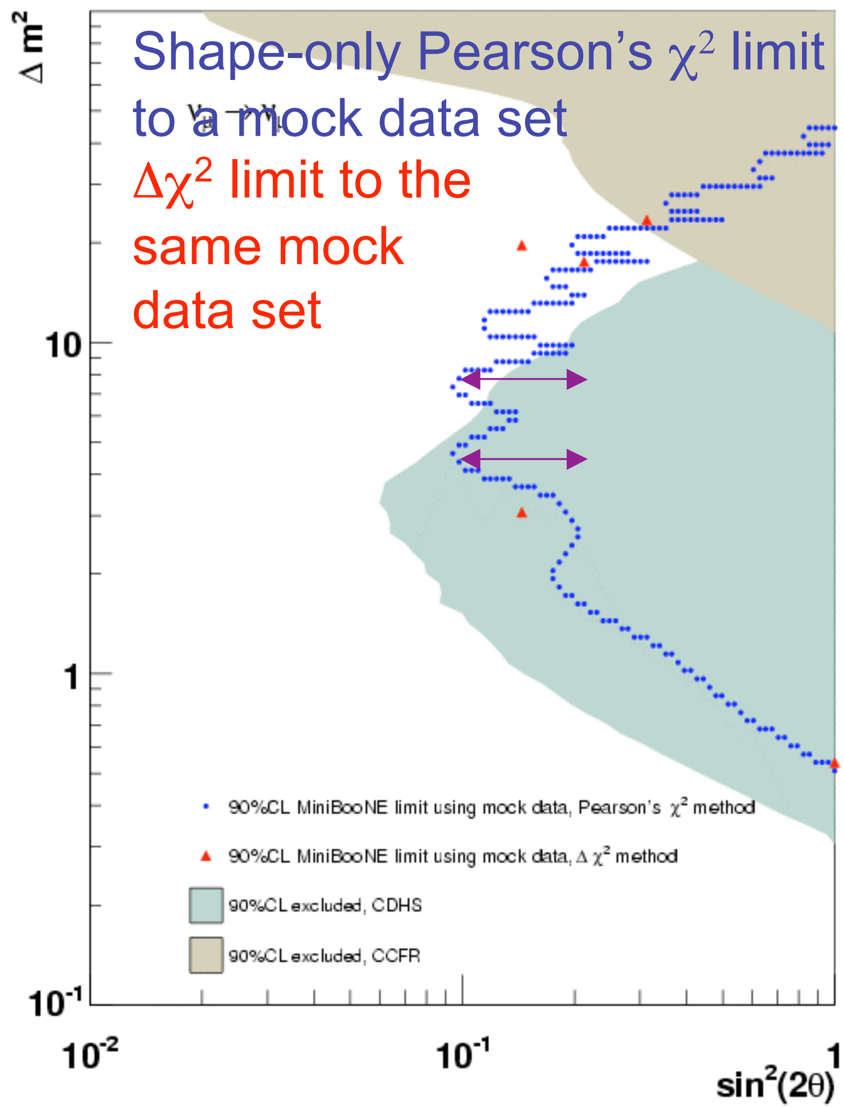
Why does the limit look weird?

For all fits, the sensitivity curve can shift rapidly across $\sin^2\theta$

We have been calling them "wiggles"

Wiggles are less pronounced in the sensitivity, but are present for any fake or real data fit



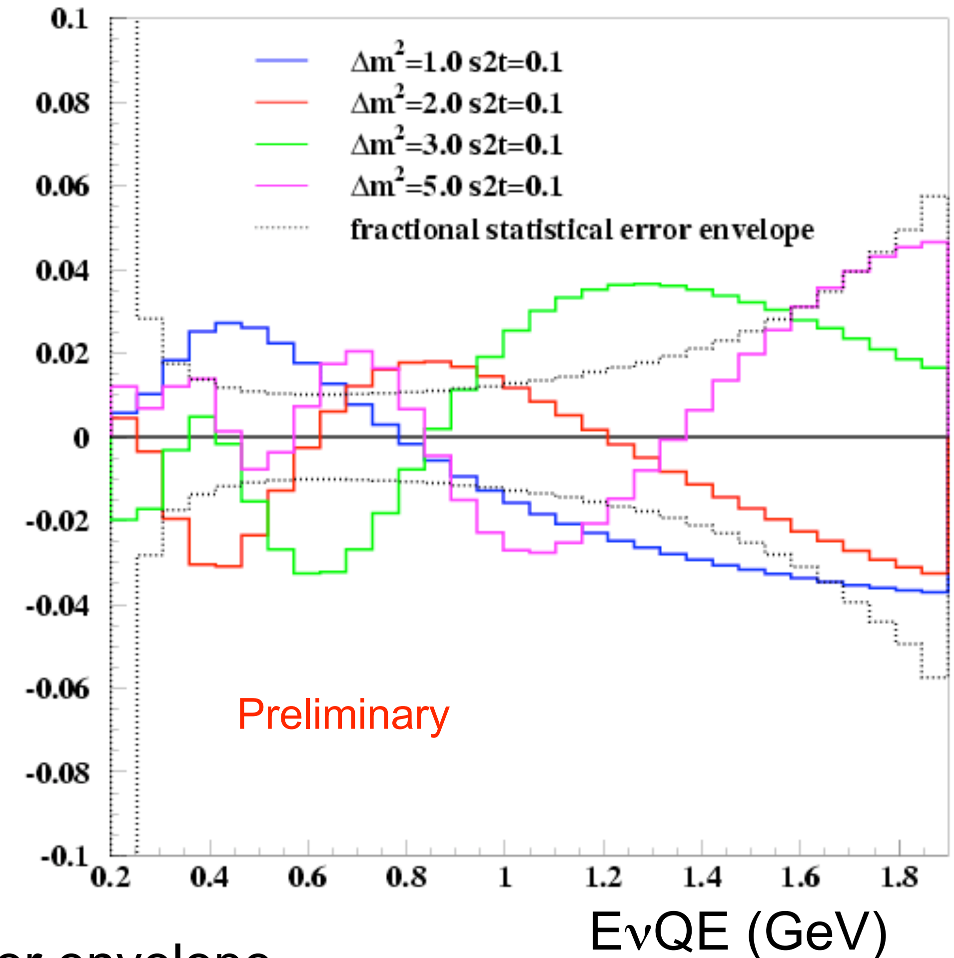


What are the wiggles?

For a fixed $\sin^2\theta$, Δm^2 close in value do not have similar behavior in EνQE

For $\sin^2\theta=0.1$, if we compare the shape of $\Delta m^2=2$ eV^2 to $\Delta m^2=3$ eV^2 we see that the $\chi^2(\Delta m^2=2) < \chi^2(\Delta m^2=3)$

The χ^2 changes with Δm^2;
a flat cut on χ^2 creates wiggles

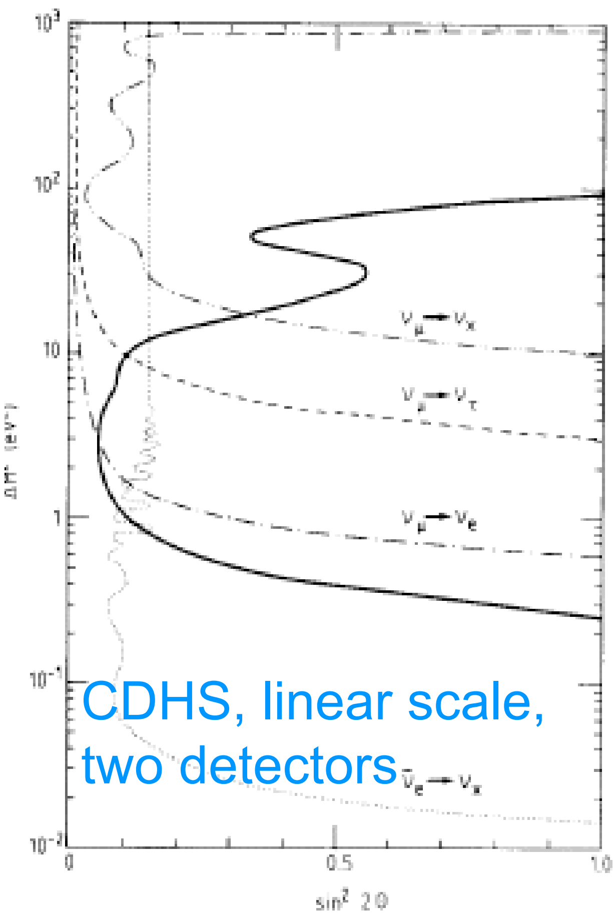


This problem is exacerbated for data fluctuations and can occur for any error envelope

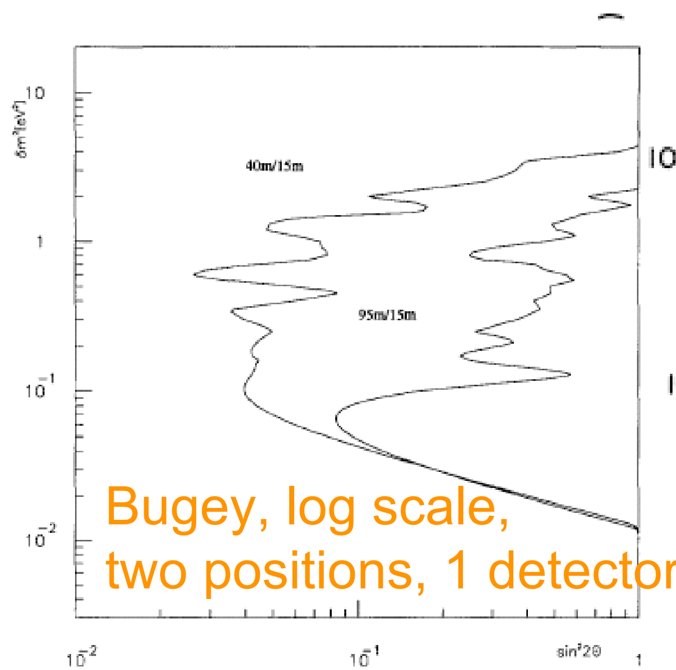
What are the wiggles?

This effect shows up in previous disappearance results even when there is a second detector

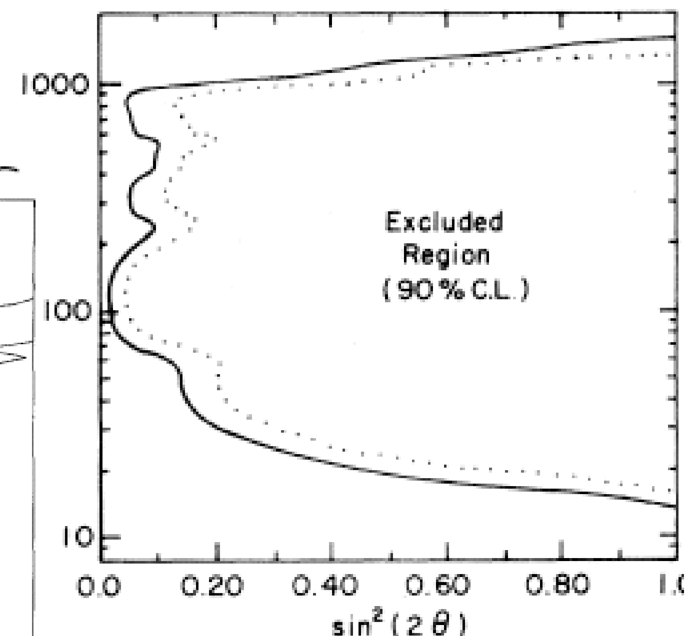
A second detector makes it harder to match L/E across all L, E but anytime it can, the χ^2 will be lower than nearby Δm^2



CDHS, linear scale, two detectors



Bugey, log scale, two positions, 1 detector



CCFR, linear scale, two detectors

ν_μ disappearance analysis plan

To do a ν_μ disappearance analysis with one detector, we need:

Event selection

+

Prediction with systematic errors

flux, cross section, detector effects

+

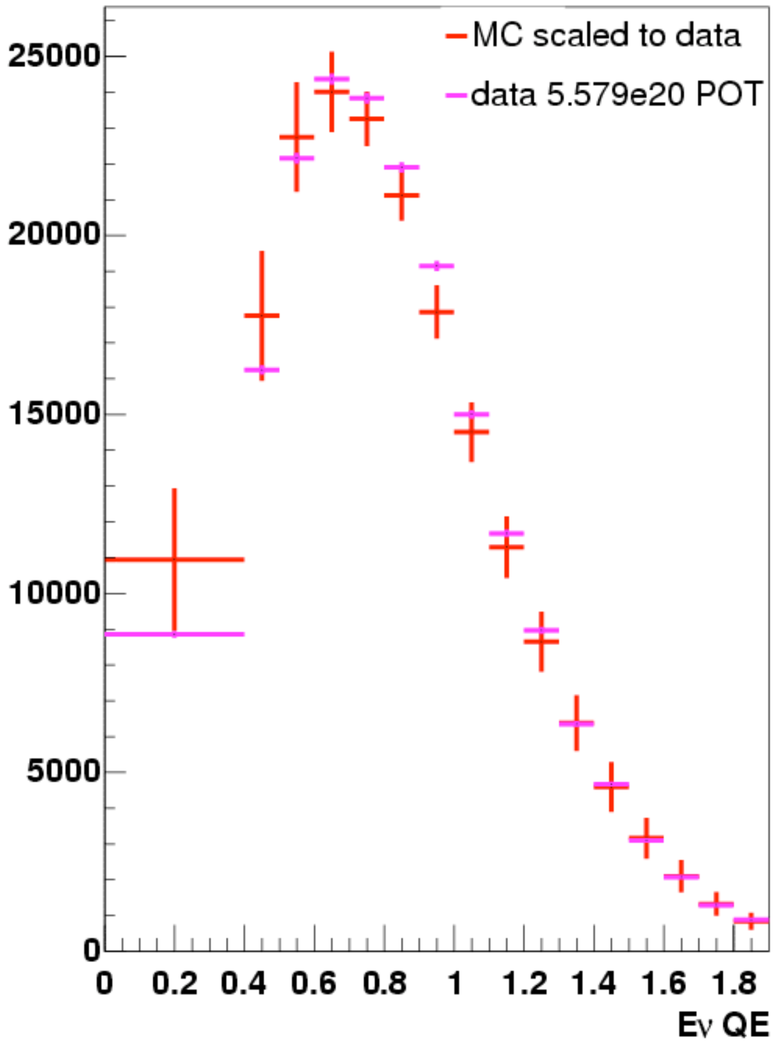
Disappearance fit machinery

=

Candy!

er, Results!

Data and null oscillation prediction



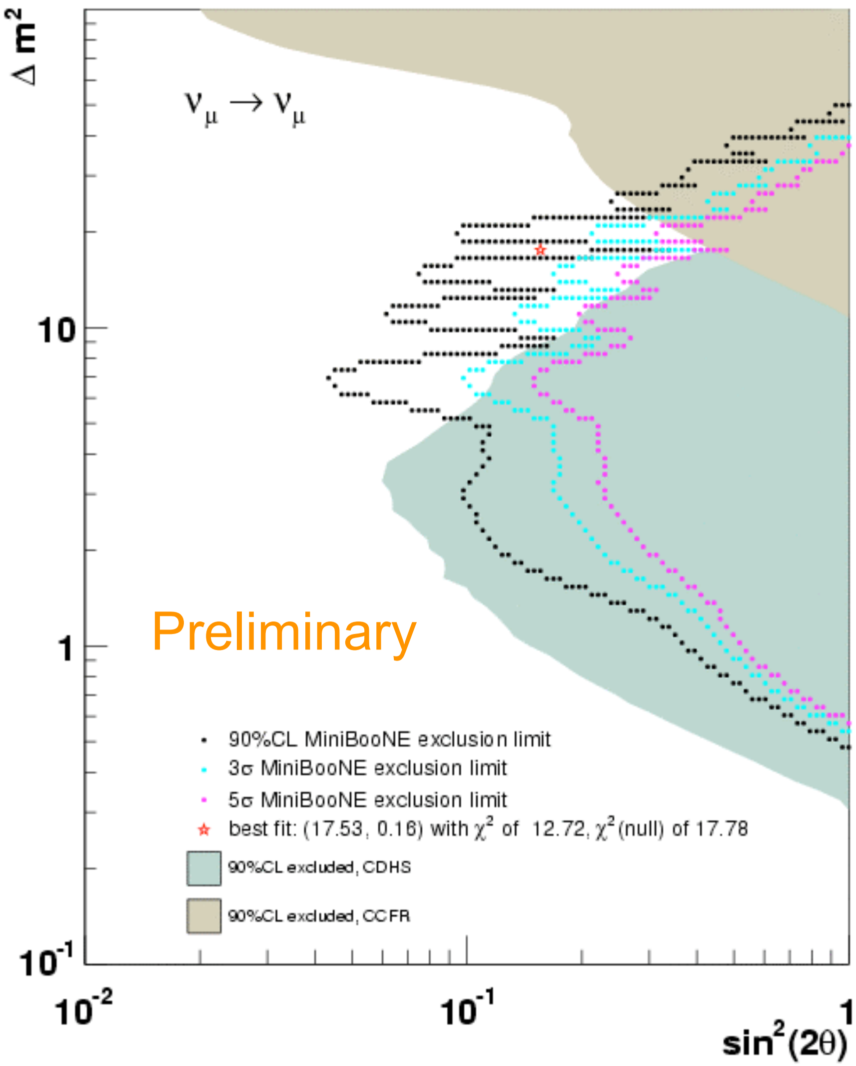
Data (5.579e20POT,statistical errors shown) with null oscillation prediction (normalized to total data) vs EνQE

Errors shown are diagonal elements of the shape-only error matrix

χ^2(null) =17.78 (34% for 16 bins)

Systematics dominate:
χ^2(null, statistics only)=665

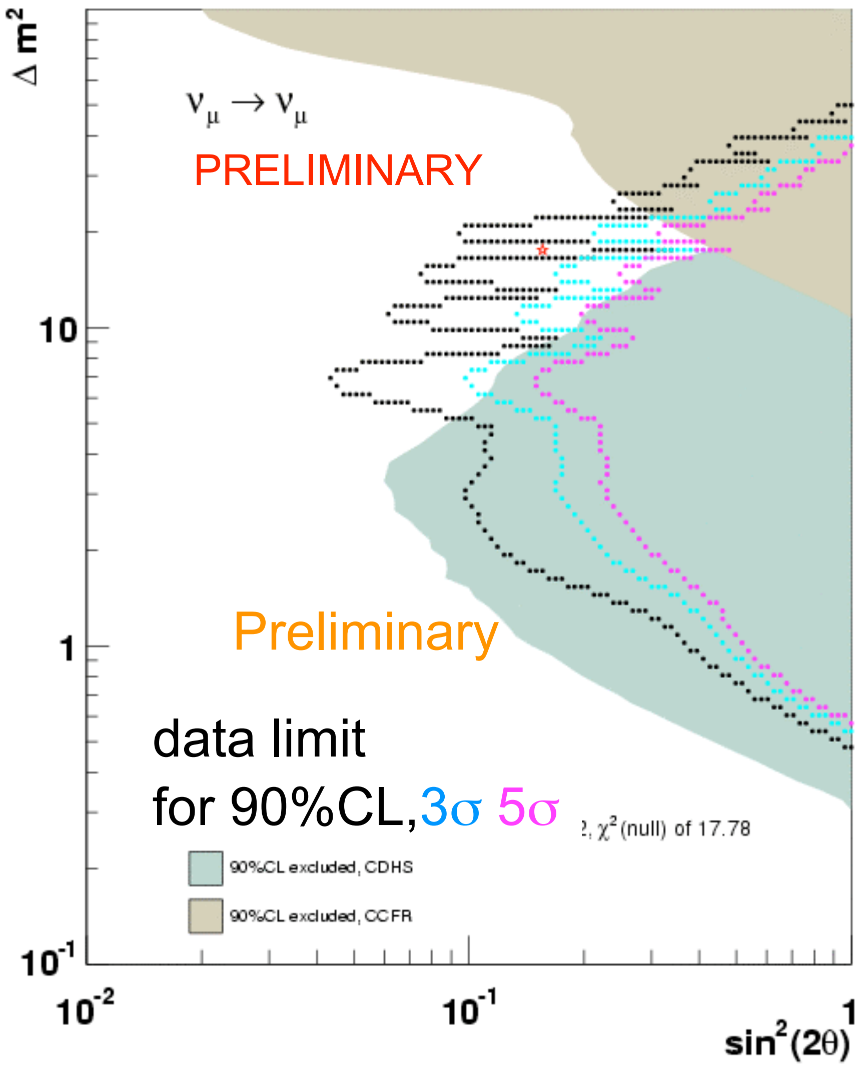
Neutrino disappearance limit

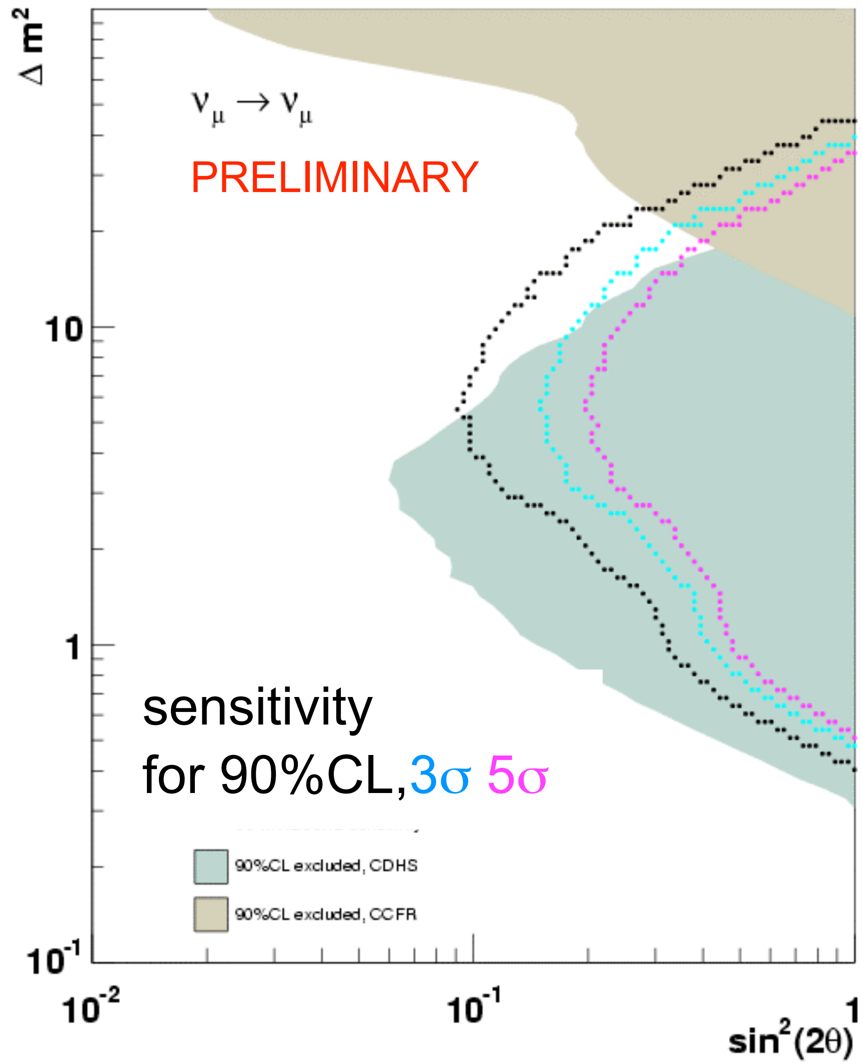


5.579E20 POT data set limit
for 90%CL, 3σ and 5σ
χ^2 (null) =17.78 (34%,16 bins)
χ^2 (min) =12.72 (69%, 16bins)
at Δm^2=17.5eV^2,$\sin^2\theta$ =0.16

MiniBooNE observes
no neutrino disappearance

Neutrino disappearance limit



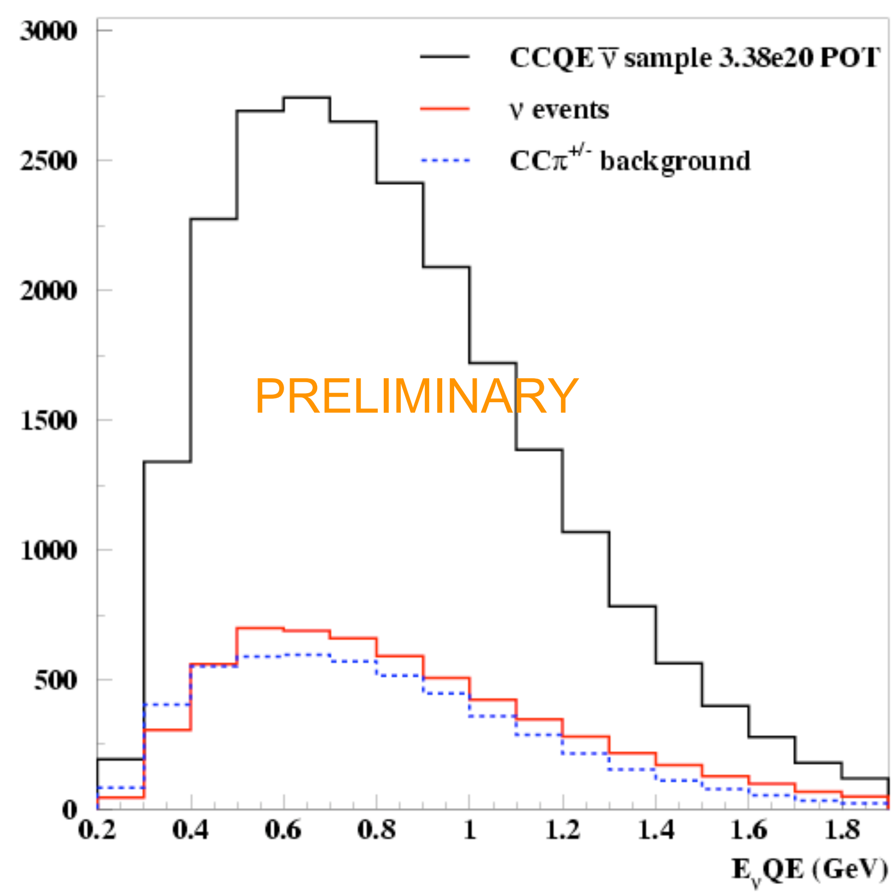


Overview

1) Neutrino oscillation
2) MiniBooNE experiment
3) MiniBooNE-only neutrino disappearance analysis
4) Antineutrino disappearance analysis
5) Improvements to disappearance analysis
6) Conclusion

Antineutrino CCQE sample

- Ability to change polarity of horn allows us to focus negative mesons and produce an antineutrino beam
- Apply same CCQE selection cuts, same error analysis, same fit machinery
- Main difference: Substantial neutrino events in the antineutrino sample (25%)

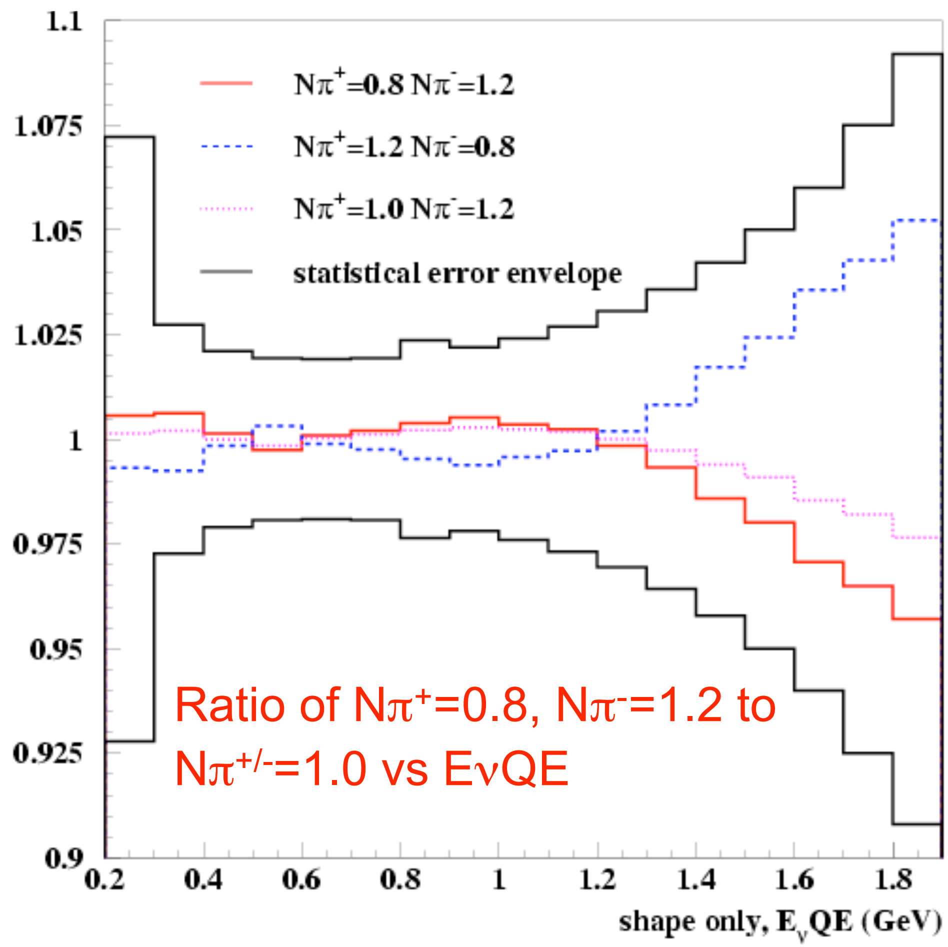


Neutrinos in antineutrino sample

Is there a shape difference between the neutrino background and the antineutrino signal?

The neutrino and antineutrino spectrums are quite similar

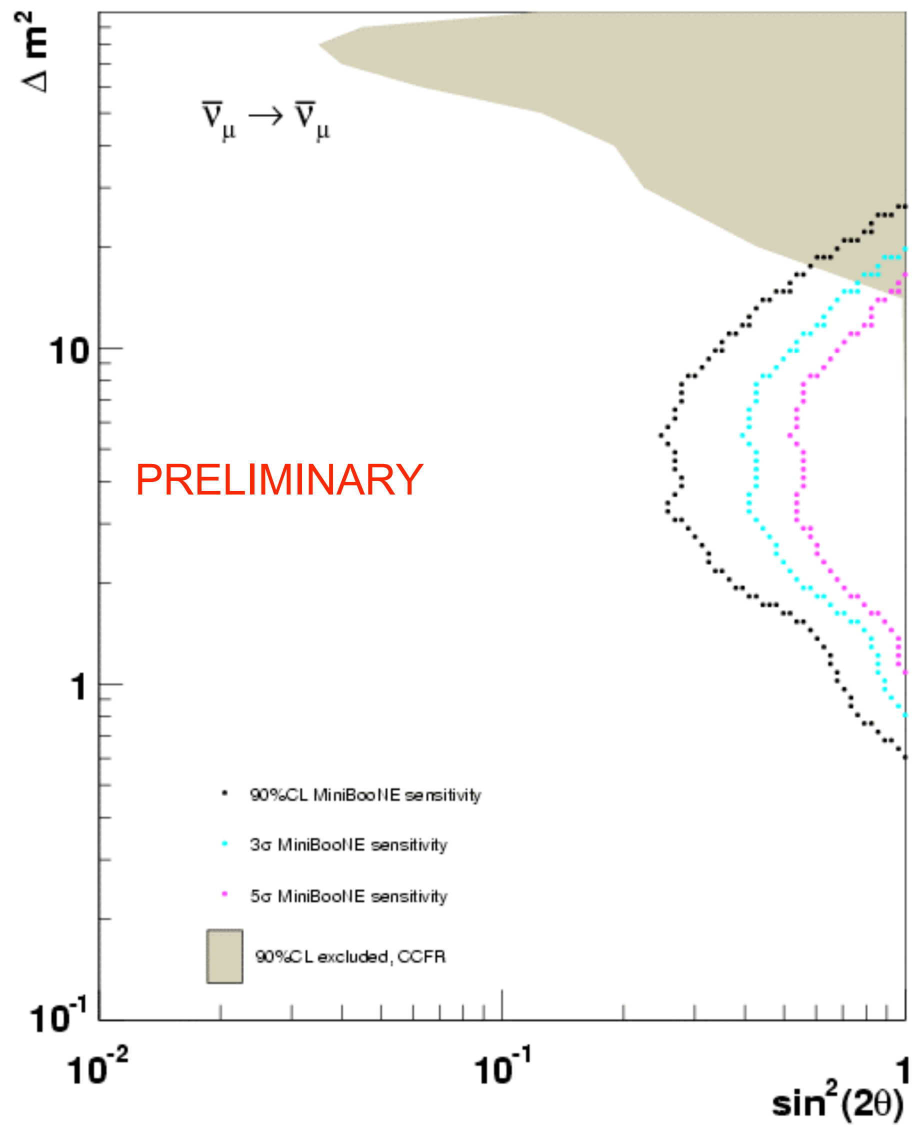
If we change the normalization of the antineutrinos ($N\pi^-$) differently from the neutrinos ($N\pi^+$), the effect on the shape of the antineutrino sample is less than the size of the statistical errors



Ratio of $N\pi^+=0.8$, $N\pi^-=1.2$ to $N\pi^{+/-}=1.0$ vs EνQE

Antineutrino disappearance sensitivity

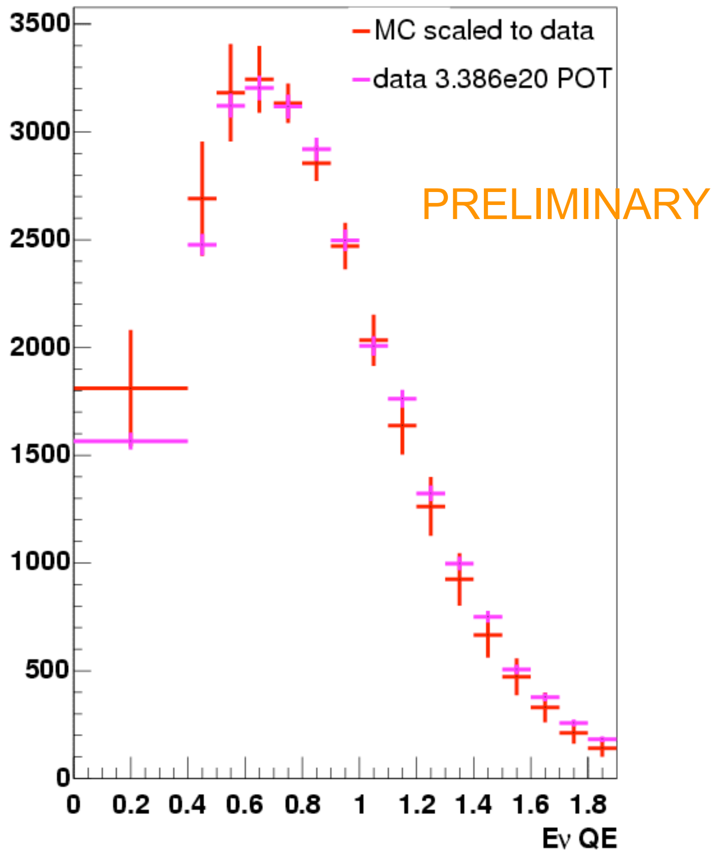
- 90% CL antineutrino disappearance sensitivity for 3.38E20 POT
- Plot assumes no ν_μ disappearance based on prior work
- Substantial new parameter space covered!

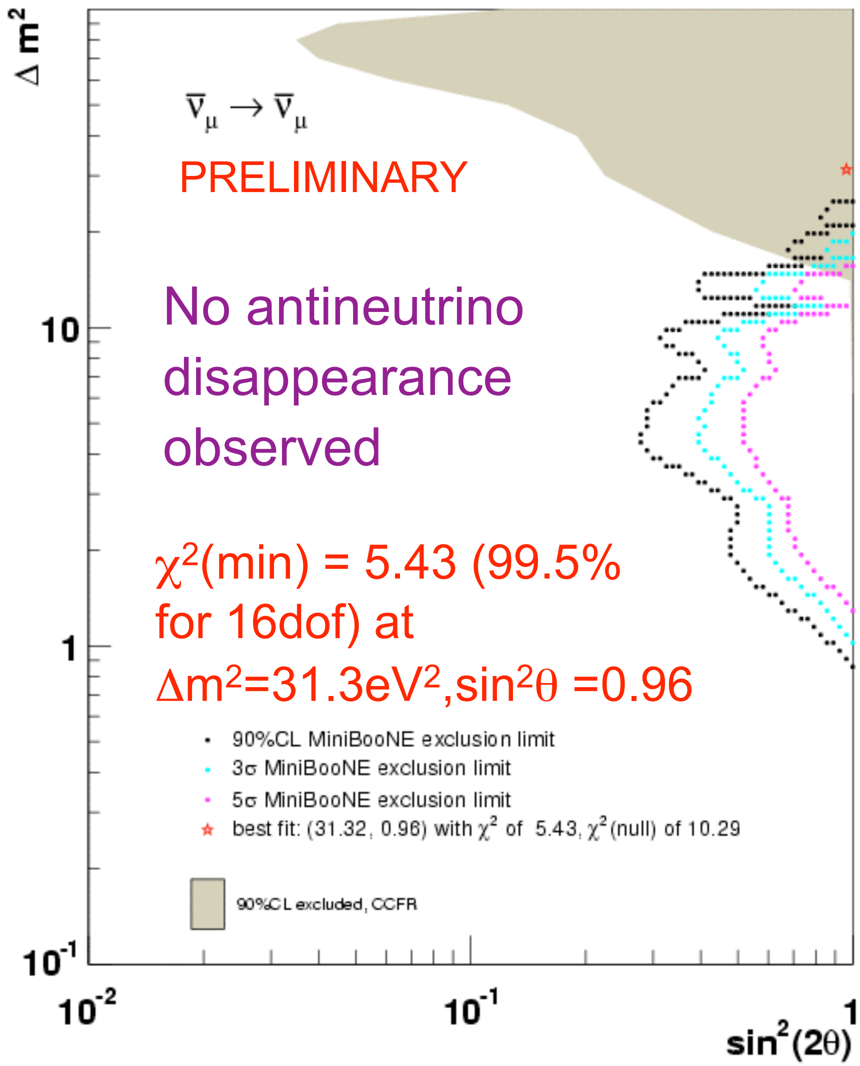


Antineutrino results!

Second dose of sugar for the day:
antineutrino disappearance results

Antineutrino disappearance results





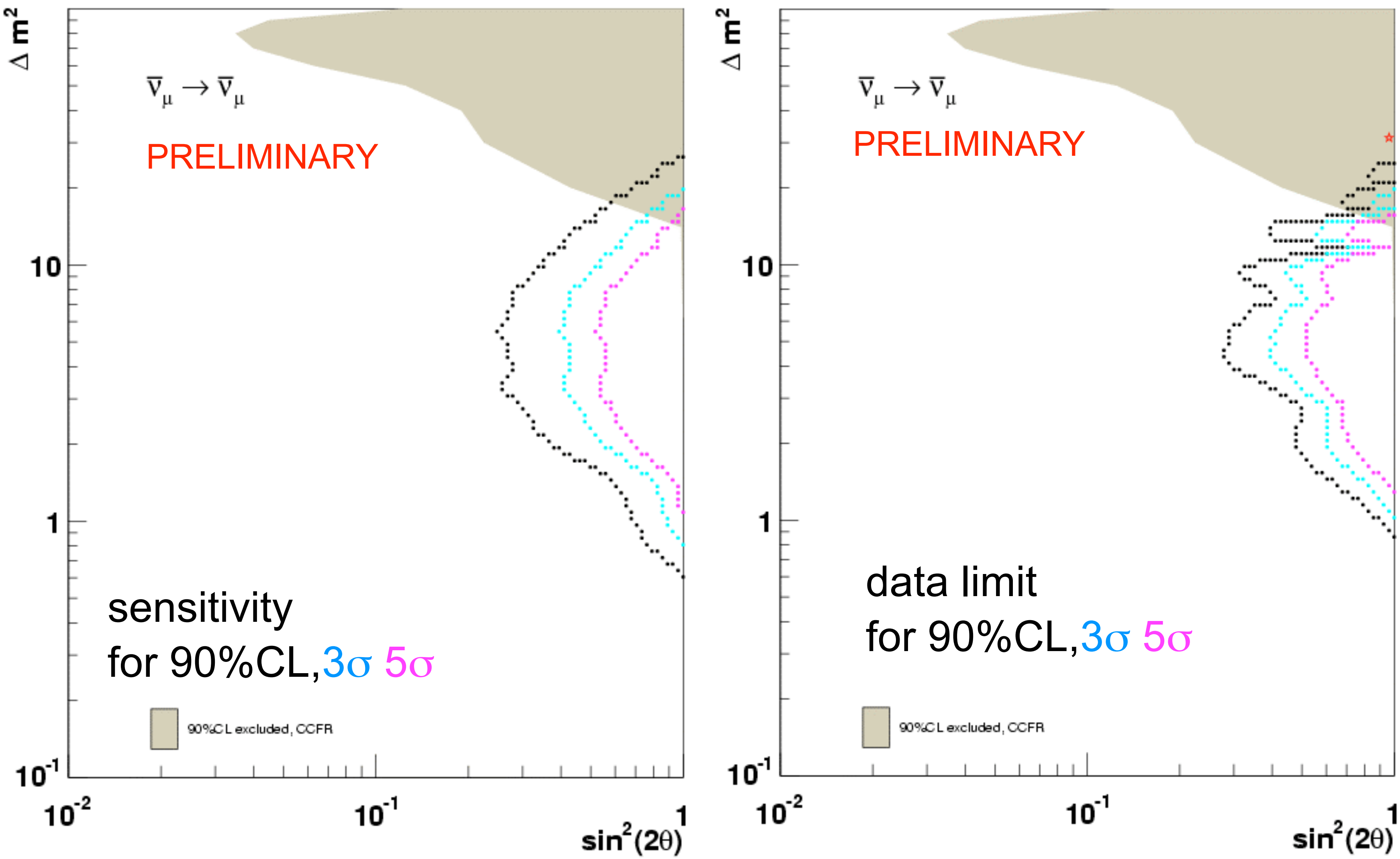
3.38e20 dataset w/ statistical errors

null oscillation w/ diagonal shape errors

χ^2(null) = 10.29 (85% for 16dof)

χ^2(null, stat only) = 109 (16dof)

Antineutrino disappearance results



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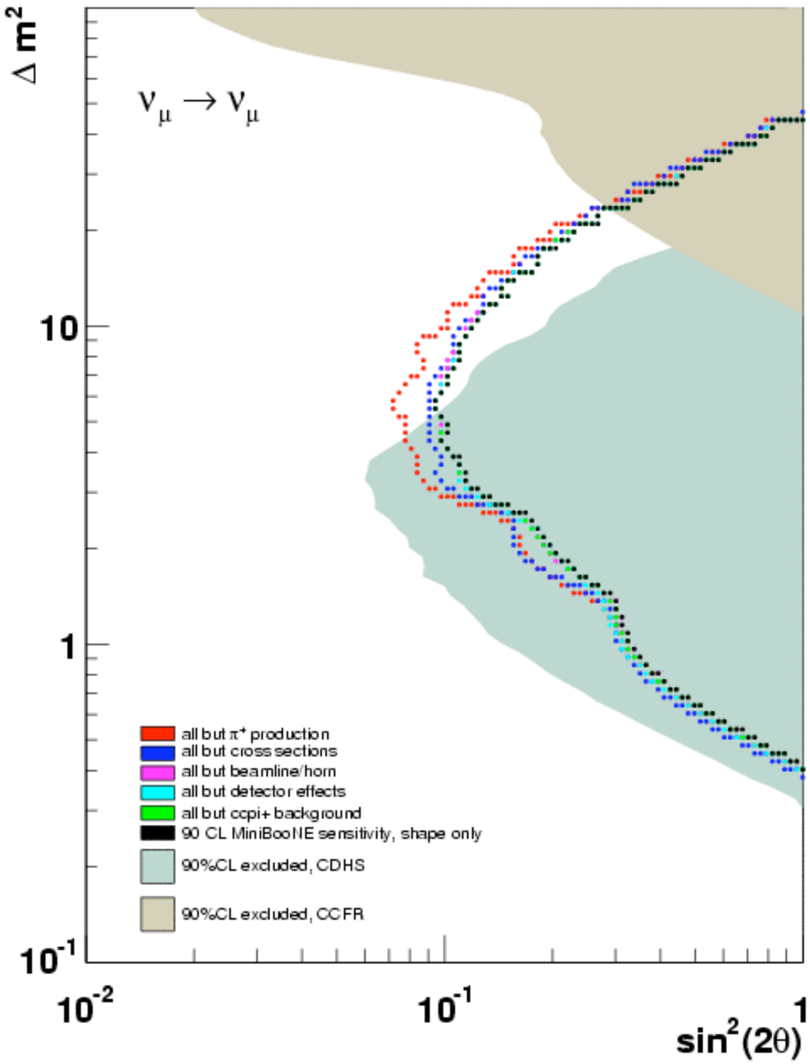
Improvements to ν_μ disappearance?



Remove each source of error one at a time, which error affects 90% shape only sensitivity most?

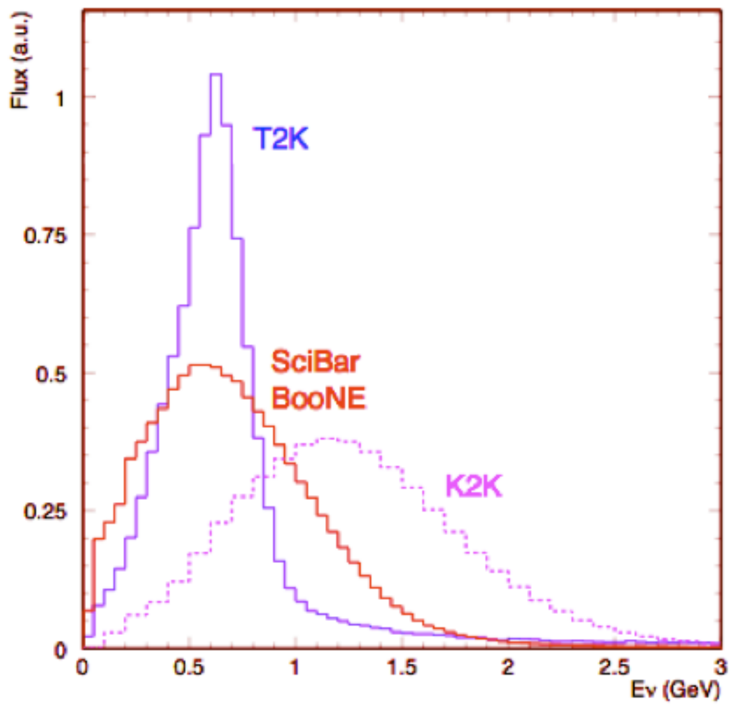
Dominant errors are flux and cross section

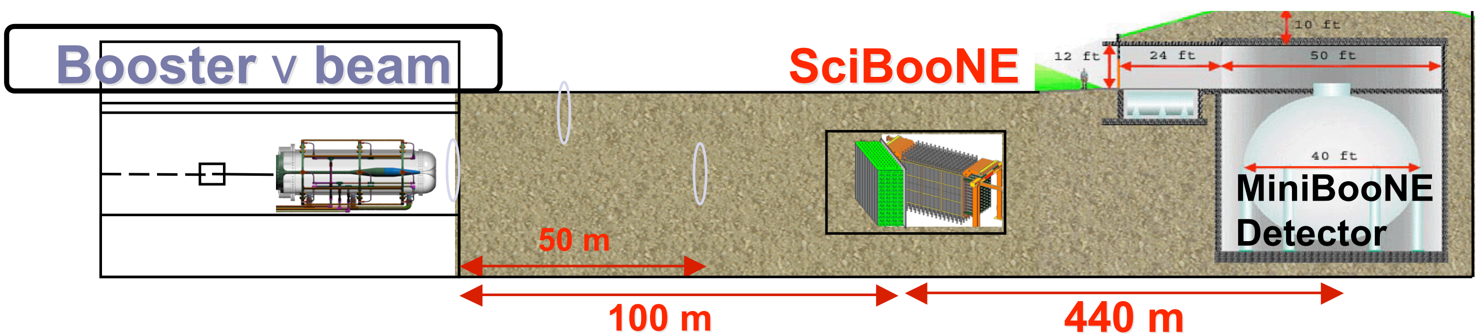
Near detector constrains both

Incorporate SciBooNE data!

SciBooNE

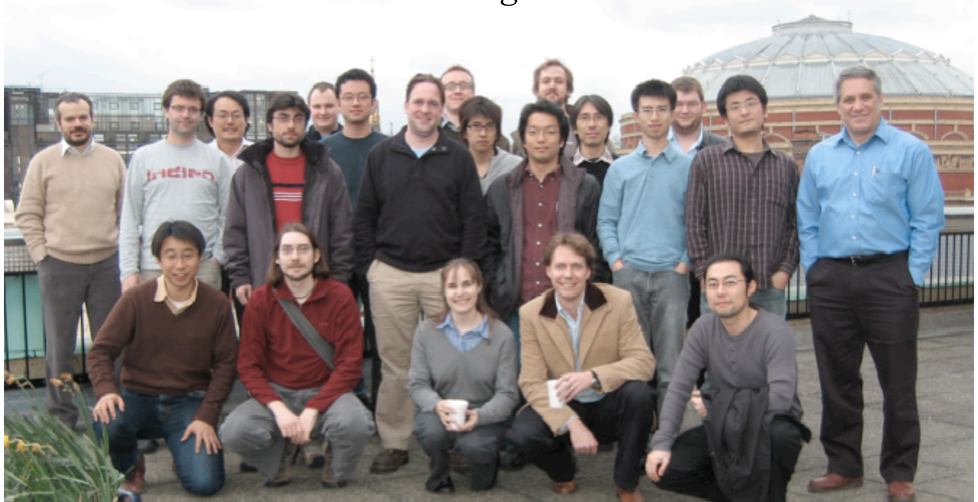
- Insert preexisting fine grained tracking detectors into Booster Neutrino Beamline
- Provide cross section information for future oscillation experiments, such as T2K
  - Similar energy range
- Also provides a near detector for MiniBooNE
  - Nearly identical flux, identical target (carbon)





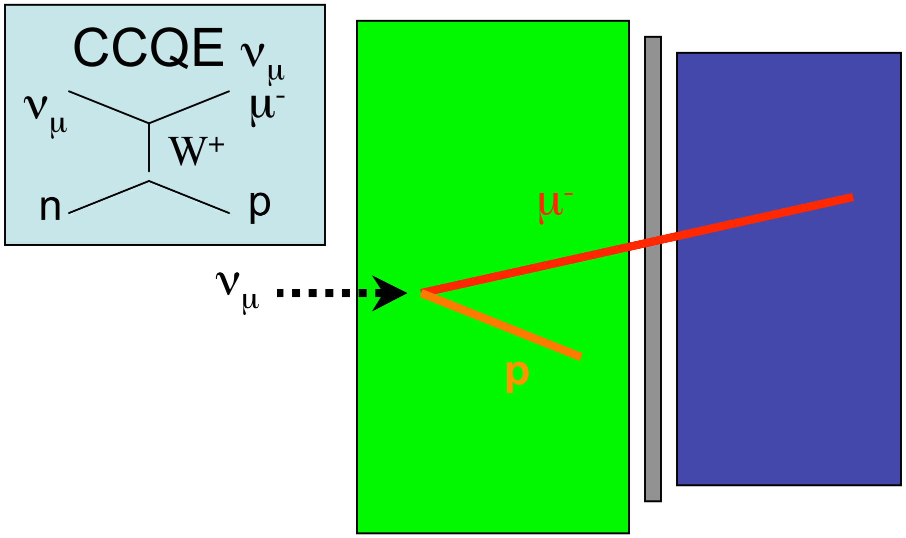
The SciBooNE collaboration

A selection of SciBooNE collaborators at the last collaboration meeting. March 2008

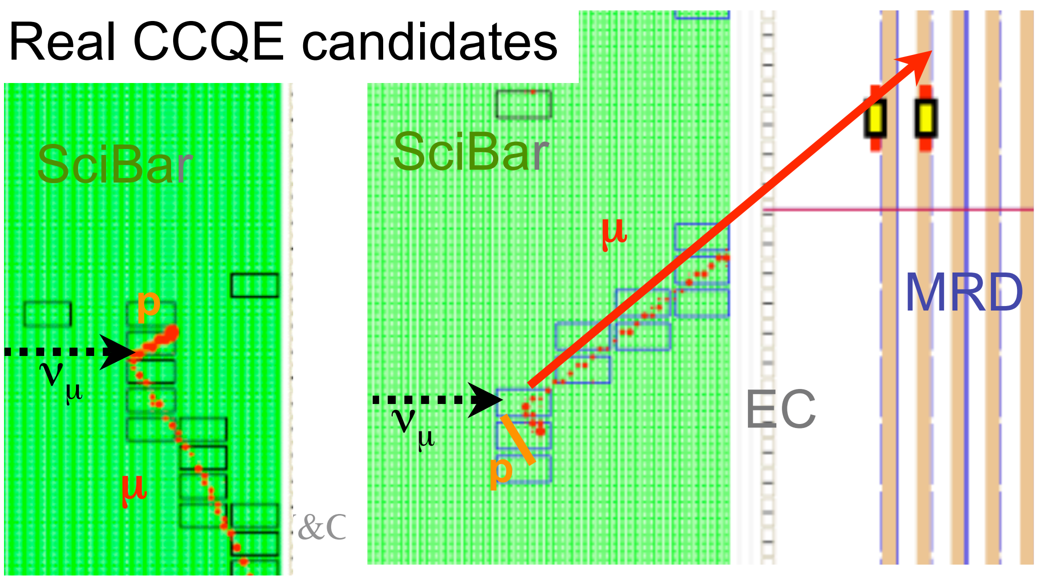


Universitat Autonoma de Barcelona
University of Cincinnati
University of Colorado
Columbia University
Fermi National Accelerator Laboratory
High Energy Accelerator Research Organization (KEK)
Imperial College London
Indiana University
Institute for Cosmic Ray Research
Kyoto University
Los Alamos National Laboratory
Louisiana State University
Purdue University Calumet
Università degli Studi di Roma and INFN-Roma
Saint Mary's University of Minnesota
Tokyo Institute of Technology
Universidad de Valencia

SciBooNE detectors

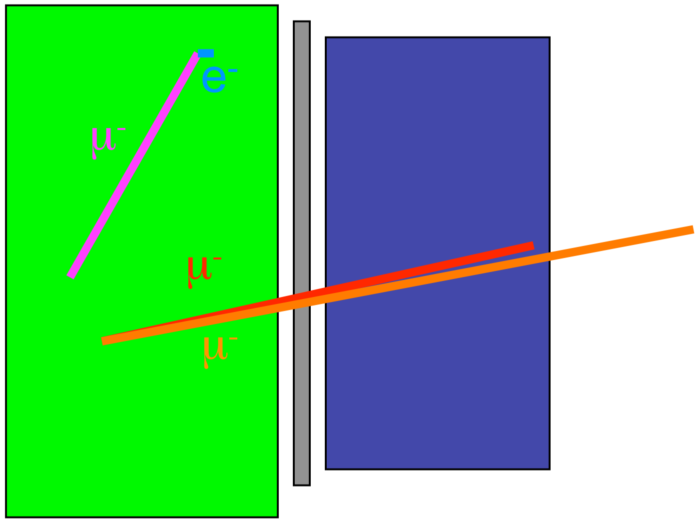


Real CCQE candidates



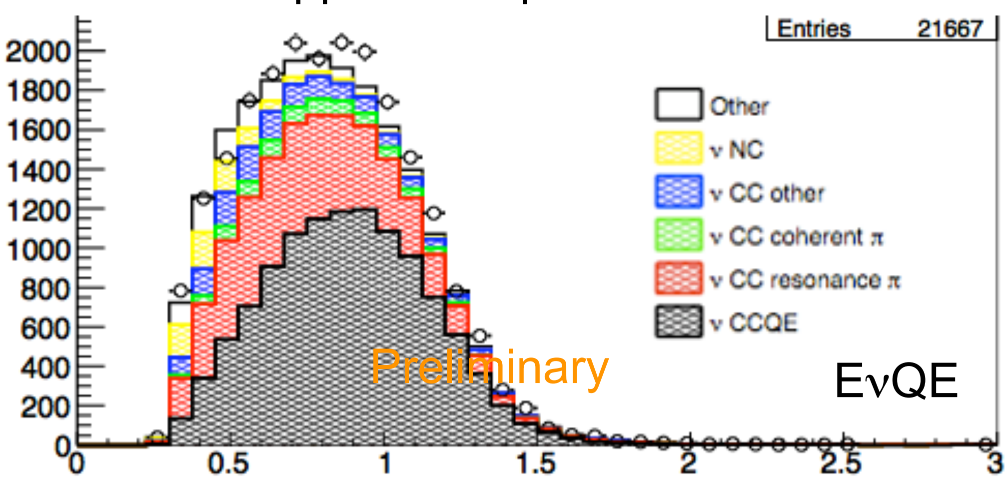
- SciBar vertex detector
  - 14,336 channel extruded scintillator with WLS fibers
  - Can use dE/dX to distinguish protons from pions, muons
  - tracks >8cm are reconstructable
- Electron Calorimeter (EC)
  - 2 plane “spaghetti” calorimeter (scintillating fiber & lead foil)
  - $11X^0$, $14\% \sqrt{E}$
- Muon range detector (MRD)
  - 362 scintillator counters, 13 alternating vertical/horizontal planes interspersed with iron
  - Measures muons < 1.2 GeV to ~10% resolution

SciBooNE data samples



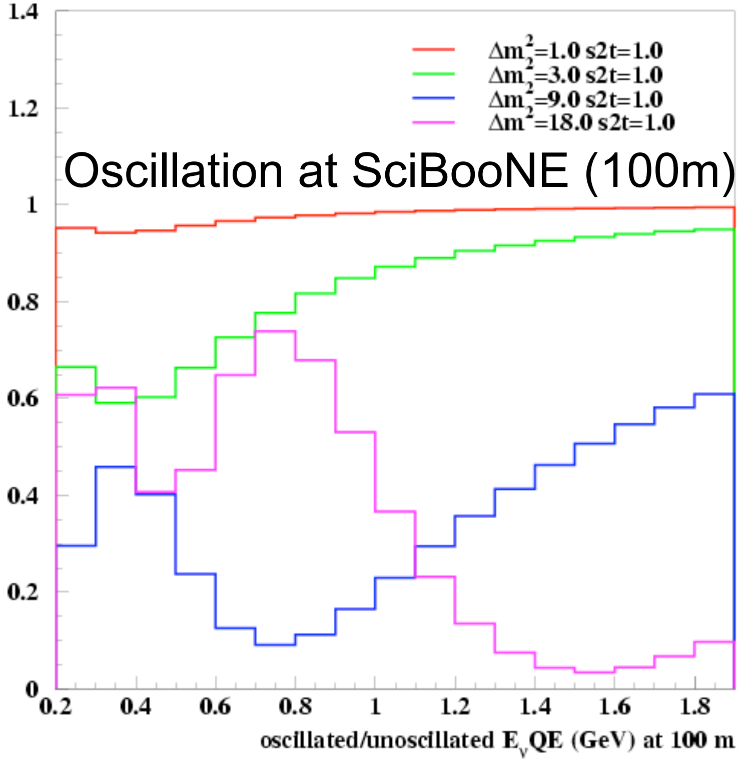
- Tag CCQE events within SciBar using decay electron
  "SciBar contained"
- Tag CC events with muon in MRD
  MRD Matched →"MRD Stopped" or "MRD Penetrated"

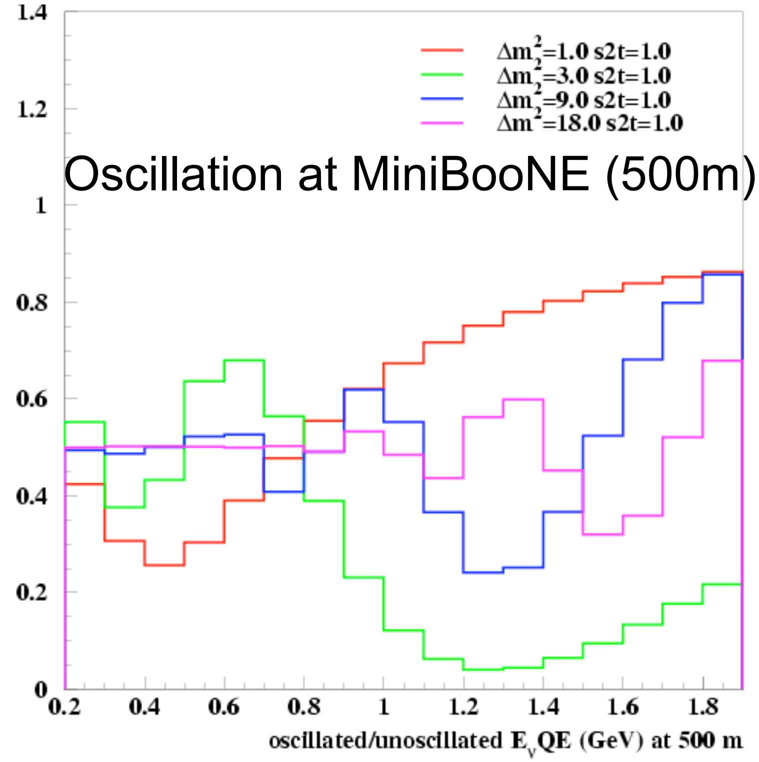
"MRD Stopped" sample



- Already developing data sets
  - neutrino mode: 0.99e20 POT
    - ~30k MRD Matched events
  - antineutrino mode:1.53e20 POT
    - ~13k MRD Matched events

Joint MiniBooNE/SciBooNE analysis





Fit will be able to include normalization information from SciBooNE

- For some oscillation signals, oscillation can be seen in SciBooNE

The flux and cross section will cancel, but the amount of correlation between the two detectors is reduced by statistics and detector errors

Conclusion

- MiniBooNE observes no neutrino or antineutrino disappearance

  Will add constraints to 3+N models

  Limits CPT violating models

- Future work will include SciBooNE as a near detector constraint on the disappearance analysis

- Additional BooNE news:

  SciBooNE has finished its first result on $CC\pi^+$ coherent production

  November 20th Wine and Cheese

  A host of MiniBooNE cross section analyses are also in the works

  - $CC\pi^+$/CCQE ratio measurement
  - NC π^0 coherent/resonant fraction for antineutrino events
  - Differential cross sections (CCQE, NC elastic, $NC\pi^0$, $CC\pi^+$, $CC\pi^0$)

  It's a treat not a trick: December Wine and Cheese with electron antineutrino appearance results!